CALIFORNIA COASTAL PROCESSES STUDY - SKYLAB

FINAL REPORT - EPN 492

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16. ABSTRACT
The Skylab imagery from S-190A, S-190B and S-192 experiments was analyzed for coastal and estuarine processes for the San Francisco Bay and the Northern California coast. In northern San Francisco Bay (San Pablo Bay) the sediment transport was traced to areas of known deposition. Information from the Skylab imagery interpretation was found to correlate closely with plots of sediment distribution obtained during the same period by boat surveys. Color composite enhancements of S-192 imagery, bands 4,6 and 7 provided detailed current and sediment transport patterns. Off the Northern California coast, the surface current patterns from the California and Davidson Currents were mapped. The S-190B color photographs provided the most useful information for this study. Close correlation between the Skylab S-190A film/filter combinations and Landsat 1 and 2 imagery provided detailed resolution of the study area not possible with Landsat alone.

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PREFACE

This report on California coastal processes using Skylab data is submitted to the National Aeronautics and Space Administration in fulfillment of contract A-85918-A. It was prepared by the U.S. Army Engineer District, San Francisco, and the Geoscience Division of Geosource Incorporated, Long Beach, California.

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NOTE: Reference numbers under each picture illustration refer to NASA project, roll and frame numbering system, i.e., NASA SL4 S190A 78-69 26 JAN 74. This letter-number combination means an image from the National Aeronautics and Space Administration Skylab 4 project, experiment S190A Multispectral Photographic Camera, frame 78-69, taken January 26, 1974. For details see Section 4.0 of this report and SKYLAB EARTH RESOURCES CATALOG (JSC 09016).

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1.0 INTRODUCTION AND SUMMARY

The objective of this study was to determine the utility of the available Skylab imagery in coastal and estuarine analyses. Although the original plan of viewing the entire coast of California was limited by coverage, the coastal reach from San Francisco to Point Delgada and the San Francisco Bay were imaged to an extent which proved to be beneficial. Complex nearshore current patterns resulting from changes in the current seasons were strikingly illustrated off the northern California coastal reach.

The San Francisco Bay estuary has a complex water movement pattern resulting from the configuration of the narrow Golden Gate entrance and the numerous bays and channels. This pattern is further complicated by the fresh water discharges of the Sacramento-San Joaquin Rivers plus minor streams and rivers. The San Francisco Bay areas large population make ever increasing demands on Bay usage that range from water contact sports through shipping, mining, fishing and waste disposal. Consequently, for comprehensive planning, the Bay is in need of study by various disciplines including: oceanography, geology, ecology, engineering, and urban planning.

The 1973-1974 winter rainy season allowed the investigators the opportunity to observe sediment transport and deposition characteristics under a high volume discharge condition. Further analyses of the sediment discharge patterns coupled with planning of navigation channel and dredging operations could result in significant maintenance savings in the future. Pinole Shoal Channel in San Francisco Bay for example must be cleared of about 460,000 cubic meters of material annually by expensive dredging operations.

In evaluating the Skylab imagery from experiments S-190A, S-190B and S-192 it was apparent which sensor combinations were most useful. The most significant characteristic was the detectability of reflectance difference in sediment laden discharge waters which were utilized as tracers in dynamic process analyses (current, tides, eddies, etc.). If only one sensor could be utilized, the S-190B color photography would be selected. It had a spatial resolution of about 15 meters and a spectral range of .4 to .7 microns. The peak of the spectral reflectance from the sediments in January 1974 was about .55 microns. This imagery permitted detection of mixing boundaries, small eddies, depositional centers and flow characteristics and allowed for defining the distribution of sediment which had been marked with tracers, redistributed and computer plotted (see Section 2.3).

Use of the S-190A multispectral photography resulted in significant information relative to both coastal processes and surrounding land and urban characteristics. The four black and white bands which closely match the Landsat bands resulted in information similar to that determined by Landsat studies (i.e., .5 - .6 microns suspended sediment features, .6 - .7 microns surface suspended sediment characteristics, .7 - .8 microns land-water boundary and maximum suspended sediment discharge and .8 - .9 microns land-water boundary). The S-190A color and color infrared (Figure 1-2) were similar to the S-190B imagery but had a poorer resolution. The majority of the conclusions resulting from this study developed from band by band interpretation of the S-190A data. Combinations of the various bands for subtraction, addition or false color enhancements provided additional information, but at significant increase in time and expense.

During the last three months of this study, the S-192 tapes became available. From the tape playback Bands 4 (Green-Yellow), 6 (Red), 7 (Infrared) and 13 (Thermal Infrared) proved to be the most useful in coastal processes studies. The tapes were converted to the VICAR format at the Jet Propulsion Laboratory, Pasadena, for playback and enhancement. All available bands were contrast stretched to enhance sediment transport features. In addition, channels 4, 6, 7 and 13 were utilized in making computer processed false color density stretched pictures of San Francisco Bay and the Northern California coast as shown in Figure 1-1. This resulted in the most useful S-192 data. Histograms which show the distribution of digital numbers within each picture provide excellent background for interpretation of density differences within each image. Noise problems included within the tape data were bothersome during interpretation, especially when trying to determine temperature differences on Band 13. Because of time and budget it was not feasibile to remove the conical line scan patterns.

The major advantage of Skylab data was the spectral coverage and resolution of the imagery. Although appropriate repetitive coverage was not available, feature detail was excellent and allowed for the coastal coverage of Pt. Reyes National Seashore, Bodega Bay and the Pt. Arena nearshore area. Information on critically eroding coastlines as well as patterns of surface currents and sediment transport were detected, and example of which is seen on Figure 1-3.

The ability to ascertain differences in sediment load, location, and extent of eddies, entrainment of riverine discharge by coastal currents and coloration difference of the sediments was possible by use of the Skylab imagery. This information will be important and useful in performing the operational requirement of ocean engineering projects. Determination of dredging sites, placement of breakwater and piers, monitoring of beach sand budgets, and coastal and estuarine sediment transport characteristics are all applicable from Skylab type imagery analyses.

Skylab presented a data source which may be utilized in the determination of the overall coastal processes at any given instant. Although precise field surveys are much more detailed, the changes in transitory coastal processes from day to day or even hour to hour during survey operations, can be significant in documenting natural processes.

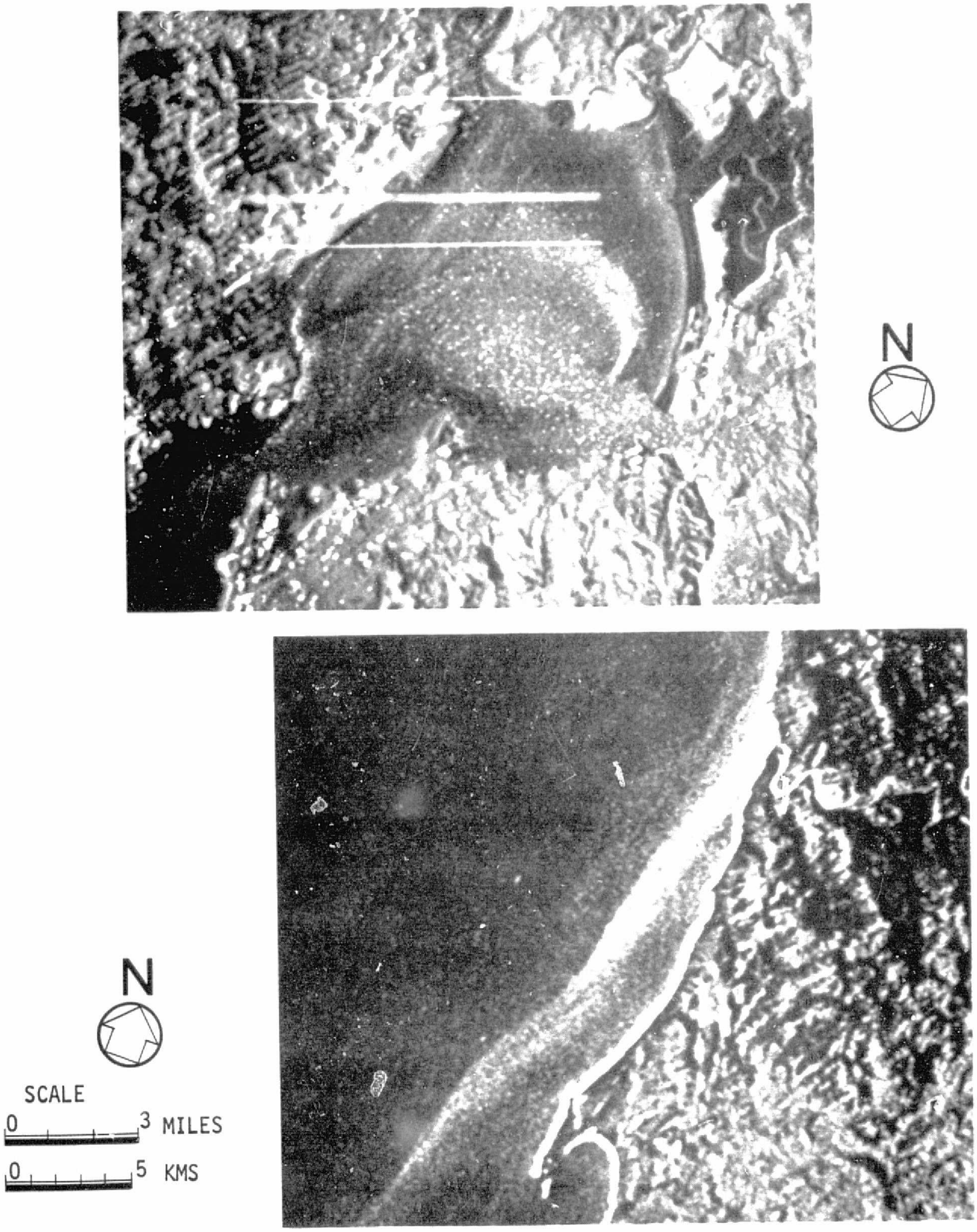

Figure 1-1. S-192 Color Composites

Color composites of San Pablo Bay (top) and the Russian River-Bodega Bay area (bottom) made from S-192 computer tape data. These enhancements were made by merging and color filtering linearly stretched Skylab computerized images of three scanner bands. Each channel was individually filtered in order to maximize sediment transport and surface current characteristics. Selected bands utilized: MSS-4 (.56-.61μm) blue filter, MSS-6 (.68-.76μm) green filter, and MSS-7 (.78-.88μm) red filter. See Section 3 for detailed explanation. NASA, SL4, 19:41:10, 26 Jan. 74, CCT

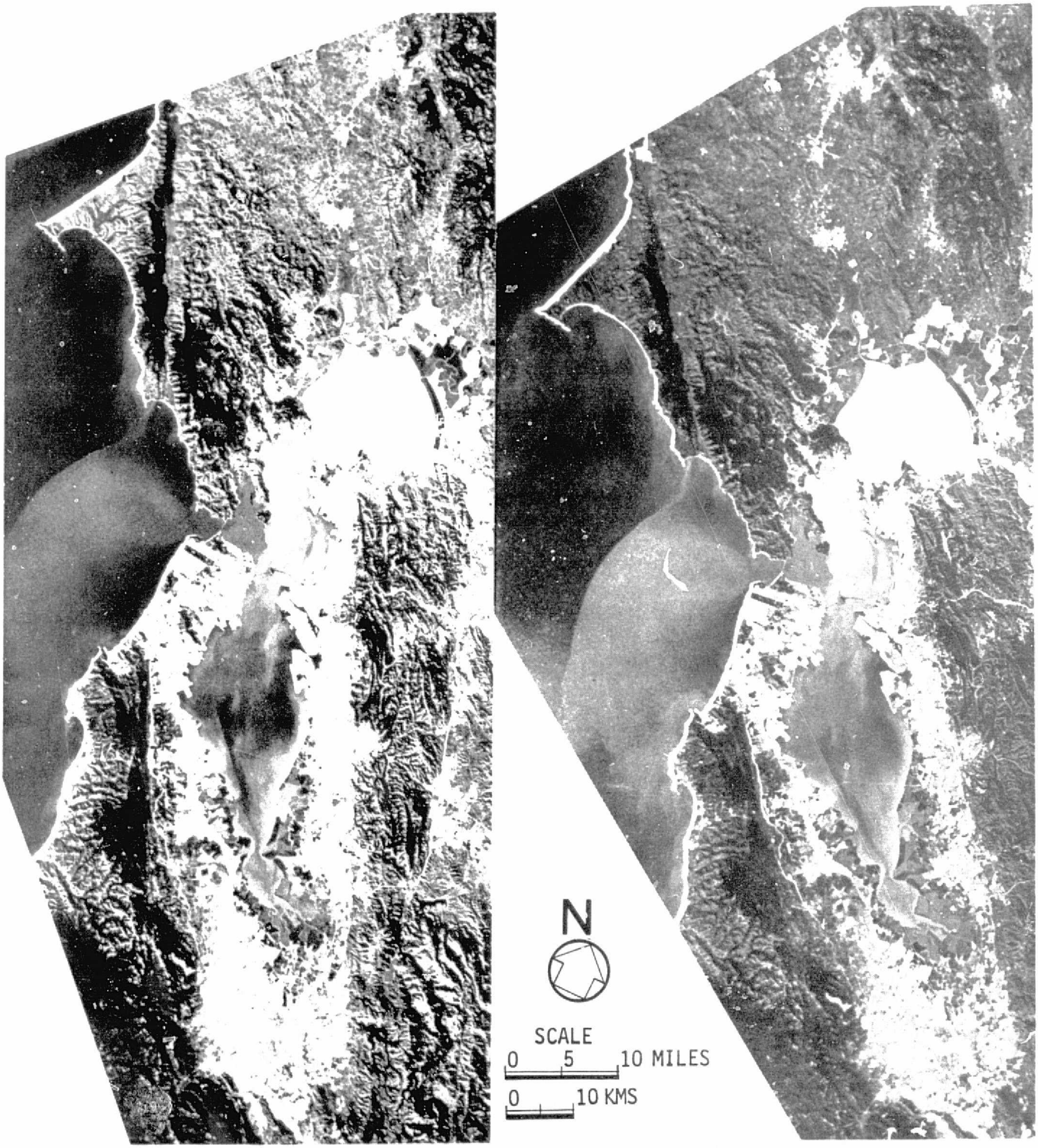

Figure 1-2. Color IR (left) and Color (right) San Francisco Bay.

Photographic detail of suspended sediment and circulation patterns present. South movement of suspended material appears outside the Golden Gate Bridge. NASA, SL4,S190A, 75-70 (right), 76-71 (left), 26 Jan 74.

Figure 1-3. Northern California Nearshore, Surface Currents, Skylab 4, 26 January 1974
Upwellings are indicated by U, current direction by arrows. .5 - .6 microns. NASA, SL4, S190A, 78-69, 26 Jan 74.

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2.0 COASTAL AND ESTUARINE PROCESSES

The coastal and estuarine processes study of the California coast was limited to areas covered by Skylab imagery. The data received from NASA included the coastal area from San Francisco Bay north past Pt. Delgada and contained many of the sites of present or potential problems relating to the effects of coastal processes. San Francisco Bay was selected as the primary study site because of Skylab coverage of the complex ocean-fresh water environment. The Bay usage is extensive and has been altered by man's often conflicting requirements. The effects of sediment transport and deposition in shipping channels and the necessity for maintenance dredging operations are of major concern to the U.S. Army Corps of Engineers.

The imagery obtained from the 26 January 1974 Skylab overpass of the northern coast of California was excellent in quality and timing. The SL-4 mission brought back a record of the complex nearshore current systems that existed during a change in oceanic seasons. Massive upwellings and meanders were imaged as the northward moving Davidson Current of the previous winter was being overpowered and submerged beneath the wind strengthened, southerly flowing, California Current. The current discontinuities caused by Point Arena, Cape Mendocino, and Point Reyes resulted in images of surface gyres, upwellings and fronts. Upwellings near submarine canyons and in the nearshore region were detected and were explained by classical oceanographic theories. Although the velocity structure of nearshore currents during transitional periods are not quantitatively known, the SL-4 Skylab imagery was able to record the qualitative structure of the surface current component.

Of all areas mentioned for coastal processes study, San Francisco Bay received the major emphasis. This was due to the coverage, present problems, public interest, and available background material. The nature of sediment transport in the Bay was under intense investigation because of the extensive dredging that is regularly conducted by the U.S. Army Corps of Engineers to maintain the existing harbors and channels within the Bay. By coincidence, the 1973-1974 runoff season, which was included in the Skylab-4 images, contained an extremely large volume of sediment discharge of approximately 6.9 million tons. The deposition of much of this sediment in the northern section of San Francisco Bay (San Pablo Bay) presented numerous dredging and shipping problems because of shoaling.

2.1 OFFSHORE CURRENTS NORTHERN CALIFORNIA

The Pacific Ocean surface current patterns off Northern California were captured in great detail in January 1974. A number of large gyres, eddies and upwellings were visible in the sediment transport system. This was the result of a complex dynamic pattern of the southerly moving California Current coming in contact with the northerly moving Davidson Current and numerous nearshore upwellings. In interpreting the nearshore processes visible in satellite imagery (Figure 2-1 and 2-2) and an interesting and significant 1:40,000 scale aircraft photographic mission, the dominant southerly and offshore surface current movements adjacent to the Pt. Arena - Shelter Cove coastal reach were realized. From comparing consecutive day's imagery on overlapping Landsat imagery and overpass data separated by 18 days, it is apparent the current and upwelling patterns sometimes remain for weeks at a time. This is also seen in viewing the Pt. Arena offshore current pattern visible on the Landsat Image (Figure 2-2) taken January 1, 1974 and Skylab image (Figure 2-1) taken January 26, 1974. The aircarft photograph which only illustrates the current pattern out to about 5 km (3 miles) shows a complex north moving current. If the aircraft imagery alone were interpreted and extrapolated further offshore an erroneous picture would result. Off Pt. Arena these patterns (see Figures 1-3, 2-1 and 2-2) are detectable out to a distance of 80 km offshore. Figures 1-3 and 2-1 are S-190A, .5 - .6 micron images while 2-2 is a Landsat image presented for comparison.

At a distance of about 45 km off Pt. Arena (Figure 2-4) a complex fingering or scalloped pattern is present on the Skylab imagery. Five fingers have formed that point seaward and bend southward at the tips. It appears that most of the material in these patterns came from river discharges north of Pt. Arena. North of Pt. Reyes (south part of picture), however, it appears that strong upwellings, most probably part of the Davidson Current dynamics, have brought colder and clearer water (darker in the image) to the surface. These upwellings have forced the sediment westward into the complex pattern seen. The south bending gyres set up at the tips of these fingers are the result of the re-establishment of the effect of the southerly moving California Current. The Landsat frame, Figure 2-2 shows a large clockwise gyre off Pt. Arena but the complex pattern shown on Skylab has not yet appeared. Such large scale patterns would be impossible to identify on aircraft imagery.

Further to the south (Figure 2-5) the Russian River discharge can be clearly traced as it moves southward and offshore. Just oceanward of this plume of material is a clear water area that appears to be an upwelling which forced a bend in the Russian River sediment plume and caused the sharp boundary to be visible. As the Russian River plume nears Pt. Reyes to the south it splits with part of the material moving offshore and part moving downcoast toward the Pt. Reyes beaches. These beaches, along Pt. Reyes National Seashore, are exposed to extreme wave and wind conditions, yet do not erode critically as they are continually replenished with the material from the Russian River discharge.

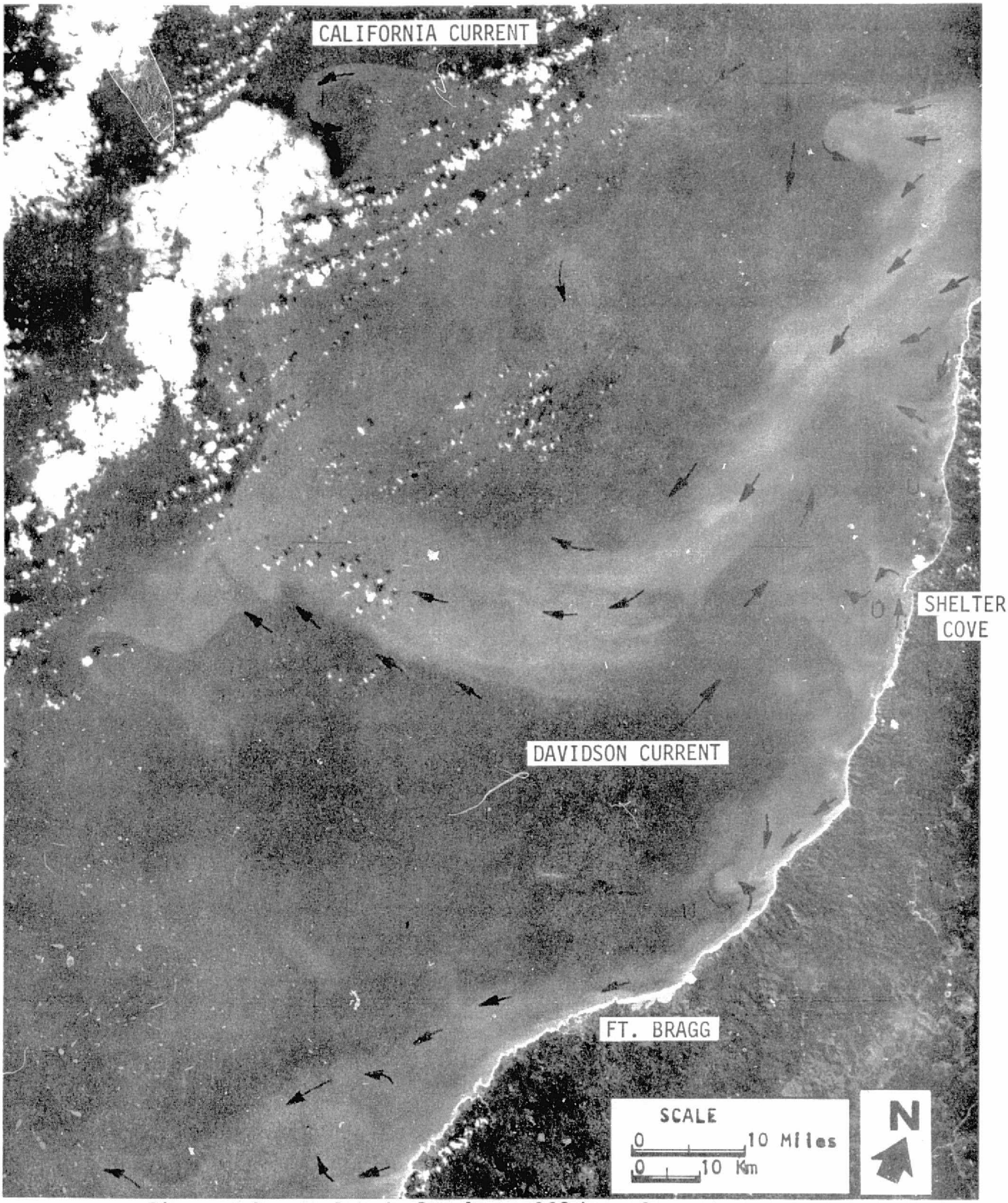

Figure 2-1. Skylab 4, Pt. Arena Offshore Currents.

Complex nearshore and offshore currents indicated by current arrows. Areas of upwelling are shown by the letter U. This January 26, 1975 is a S-190A image in the .5 - .6 micron spectral band. Offshore current at bottom of picture was present on Landsat image taken January 1, 1975. NASA, SL4, S190A, 78-68, 26 Jan 74.

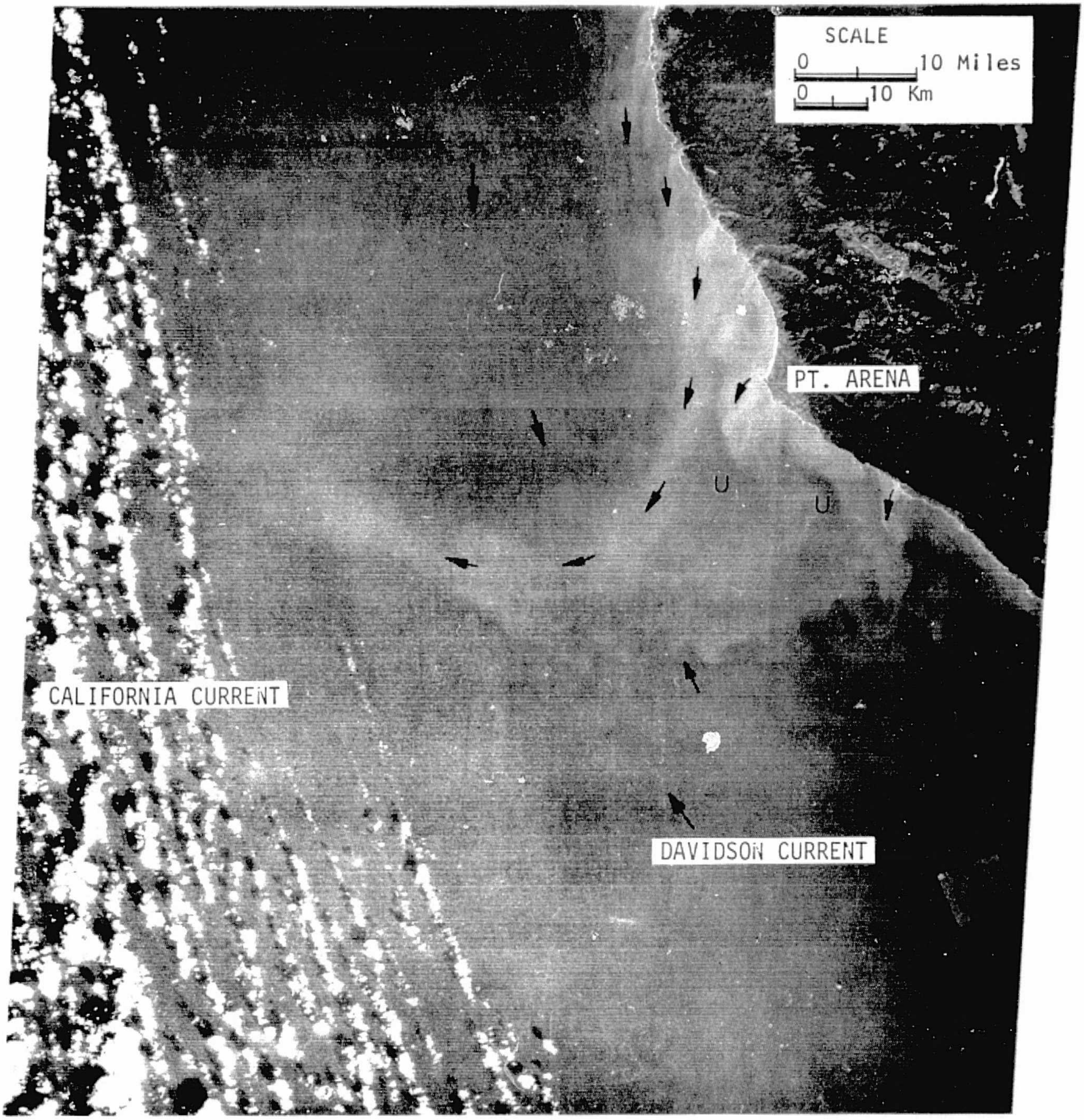

Figure 2-2. Landsat image of Pt. Arena, January 1, 1974.

Upwelling (U) and current direction arrows are indicated. A complex system of mixing and meandering eddies are clearly visible. The offshore current near Pt. Arena was located near this spot for almost all of January. NASA, ERTS-1 (LANDSAT 1), 1527-18255-4

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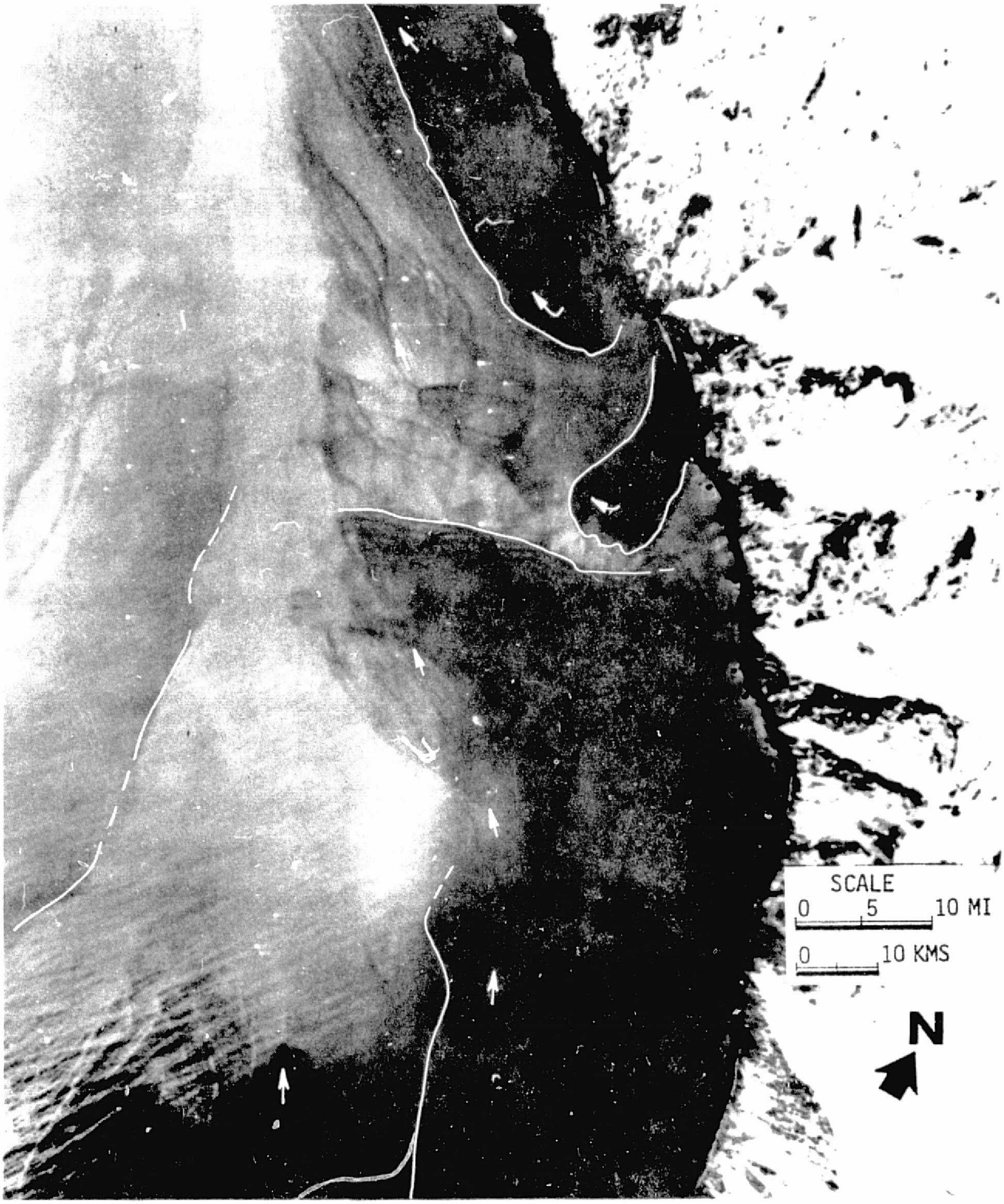


Figure 2-3. Sediment transport near Shelter Cove, Northern California.

North moving nearshore current patterns are visible in this 1:40,000 scale aircraft photograph taken January 27, 1974 during NASA mission 259. This print was made from a color transparency original. Dark shades of gray represent maximum sediment, light-minimum sediment. Arrows indicate current direction. Sediment transport boundaries are also indicated. NASA Mission 259, 97-94, 27 Jan 1974.

Figure 2-4. Pt. Arena area of Northern California. January 26, 1974

The eddy pattern at Pt. Arena is visible as longshore currents move suspended sediments in the southerly direction. Offshore swirl and boundary patterns are present indicating a slow moving California Current. Upwellings (U) and current directions (arrows) are indicated. Five fingers or scalloped patterns are present offshore on this color photograph. NASA, SL4, S-190B, 92-333, 26 Jan 74. Lift color photograph for feature description.

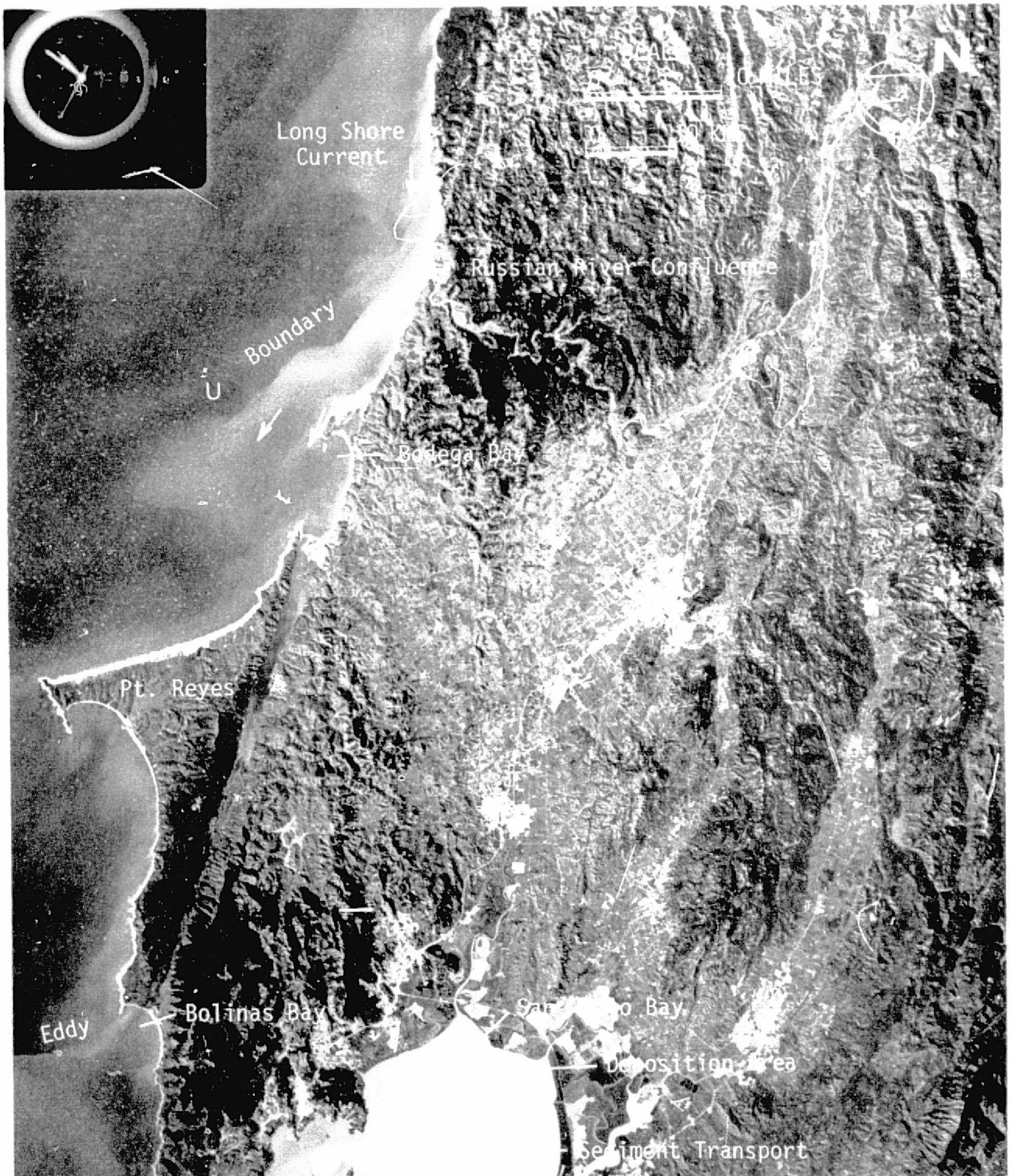


Figure 2-5. SKYLAB S190-B Northern California.

The southerly moving California Current and the gyering effect caused by headlands is illustrated in detail. Sediment transport near Bodega and Bolinas Bays is also visible on this color photograph. NASA, SL4, S-190B, 92-335, 26 Jan 74. Lift color photograph if present for feature description.

2.2 SAN FRANCISCO BAY

Sediment which reaches San Francisco Bay comes from a drainage basin area of more than 130,000 square kilometers. The region includes the Great Central Valley of California, drained by the Sacramento-San Joaquin River systems. These rivers flow into the San Pablo Bay from the Sacramento Delta, along with smaller streams flowing directly into the bay from the surrounding hills. The rivers of the Central Valley which deliver sediment to the Bay through Carquinez Strait (Figure 2-6) contributed about 82 percent of the total volume, whereas the local streams are responsible for about 18 percent of the total sediment inflow.

The greatest accumulation of sediment occurs in the San Pablo Bay, the first major embayment encountered by the comparatively large mass of suspended material carried by the delta outflow. During periods of high surface runoff, such as those which occurred in the winter of 1973-1974, the greatest loads of sediment are transported into the Bay system. The fresh water flow first encounters the saline water of the ocean in Carquinez Strait and San Pablo Bay. Where fresh and saline water meet, flocculation occurs with subsequent deposition of much of the clay and silt material.

River waters tend to flow oceanward over the intruding ocean water to produce a stratified condition. The location of the mixing region changes with the fresh water outflows and tide, and extends from the open ocean outside the Golden Gate Bridge to upstream from the Carquinez Strait. Central San Francisco Bay, San Pablo Strait, and San Pablo Bay are all included in this zone.

The flow patterns in the San Francisco Bay system resulting from the ocean tides, cause continual vertical mixing so there is a gradual transition of salinity with distance in the Bay. On January 26, 1974, at 1141 Pacific Standard Time (PST), the excellent Skylab 4 imagery seen in Figure 2-7 was taken. At the Golden Gate Bridge, a high tide occurred at 1254 of 1.52 meters. This means flood tide was still taking place at the time of the overpass. The tidal current at the Golden Gate Bridge was within 17 minutes of maximum at a velocity of 1.2 meters per second. Because of the difference in tidal movement within the Bay, however, the conditions seen on the Skylab imagery at the Carquinez Strait were significantly different. Although this area is only 30 km from the Golden Gate Bridge, it was 2 hours 54 minutes before high tide. The tidal current was flooding slowly eastward at a velocity of about 0.1 meters per second.

The currents in the Bay are important to the study of sediment transport. They are complex because of the configuration and bathymetry of the several bays and straits. These configurations, sometimes abrupt, bring about the peculiarities of phasing, the differences in tidal ranges and the wide diversity in patterns and strengths of the tidal currents inside as well as outside the Bay. Seaward of the Golden Gate, the current is normally rotary in a clockwise direction.

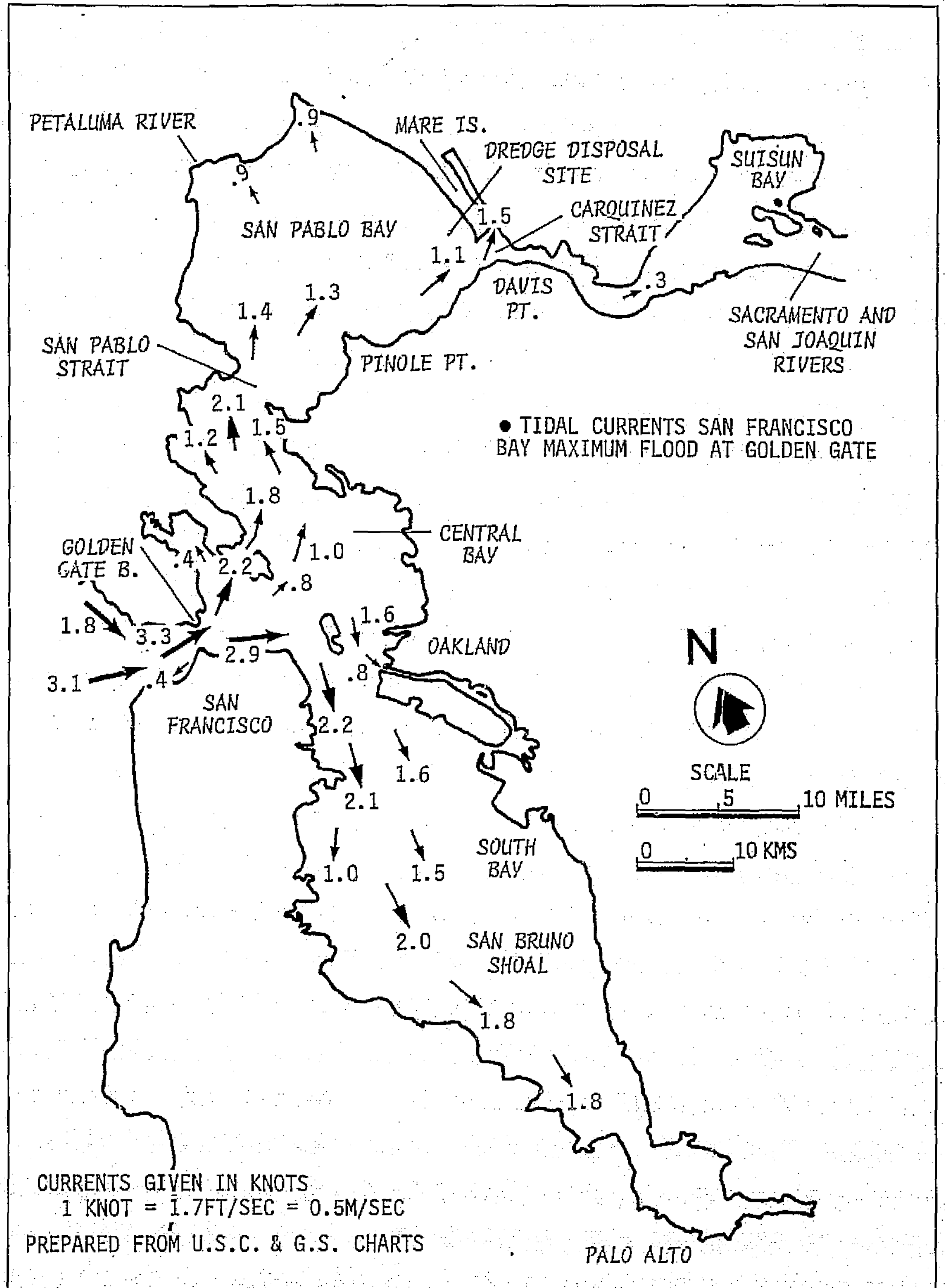


Figure 2-6. San Francisco Bay Tidal Currents from Smith, 1966.

In San Pablo Bay the maximum velocities occur in the deep water channels with velocities from 0.76 to 1.03 meters per second on the ebb, but are reduced to 0.42 meters per second for both ebb and flood in the shallow area. The current velocities are not uniform throughout the depth of flow. Velocities at the surface are somewhat faster than at mid-depth and considerably faster than bottom velocities where the drag effect of friction is noticeable. Density difference, however, can account for variations in top and bottom velocities particularly in an estuary where the heavier saline flows at the bottom have a longer flood duration and so bring about two-way surface flow. This occurs in the Carquinez Strait where less dense fresh water surface current is downstream simultaneously with denser bottom currents upstream.

The sediment discharge as seen in Figure 2-7 has a main channel component and two side prongs which are discussed in some detail in Section 2.4 on Analysis of Dredge Disposal. It will suffice to note here that the Skylab 4 imagery from January 26, 1974, clearly illustrates surface discharge. The deposition pattern of these sediments as seen on Figure 2-8 closely matches this pattern. The main channel is the area of initial and secondary deposition where little or no resuspension occurs. This is also the area which requires expensive dredging. Between the main channel and the shallow shoaling sites is an area subject to deposition where limited resuspension and removal occurs as a result of tidal currents and wind induced wave motion. The shoals are thickly deposited with river sediments. Because of the shallow water over the shoal, significant resuspension and movement occur.

2.3 SUSPENDED SEDIMENT DETECTION - SAN FRANCISCO BAY

The distribution and volume of sediment present in suspension during the Skylab 4 overpass was studied for San Pablo Bay and the Carquinez Strait. Densitometric measurements of the 190A color imagery were made in both the unfiltered and filtered mode and by utilizing three 200A bandwidth filters (4900A, 5300A and 5900A). The density plots show a good correlation to the turbidity measurements taken in San Pablo Bay and raster plots of sediment distribution within the Bay itself. The turbidity plots were all made within three to four days of the Skylab overpass. Outflow during this period from the Sacramento-San Joaquin Rivers was constant, thus comparisons of sediment distributions are valid. The monthly plots (Section 2.4) are the result of the U.S. Army Corps of Engineers Dredge Disposal Study for San Francisco Bay and Estuary (Sustar, 1975). Dredged sediments were marked with an iridium tracer. Loads of marked disposal material were dropped into the San Pablo Bay 4.8 km off the Mare Island Breakwater. This disposal took place during and soon after the Skylab overpass. The distribution of these sediments were then determined by monthly collection of samples at numerous grid sites throughout the North Bay area (82 in San Pablo Bay). The plots for May, June and July, which are included with this report, reflect the patterns of sediment distribution graphically shown on the Skylab imagery.

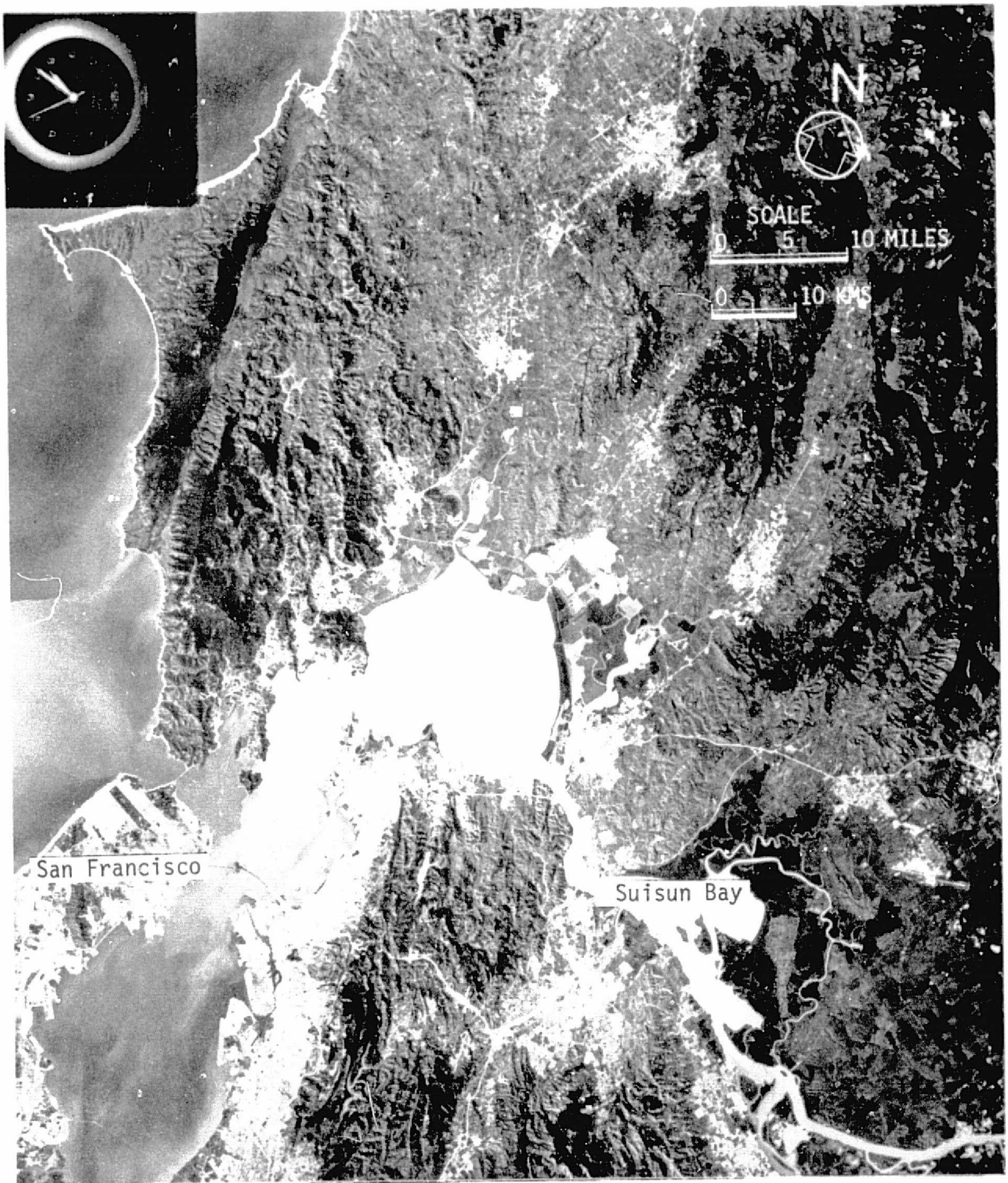
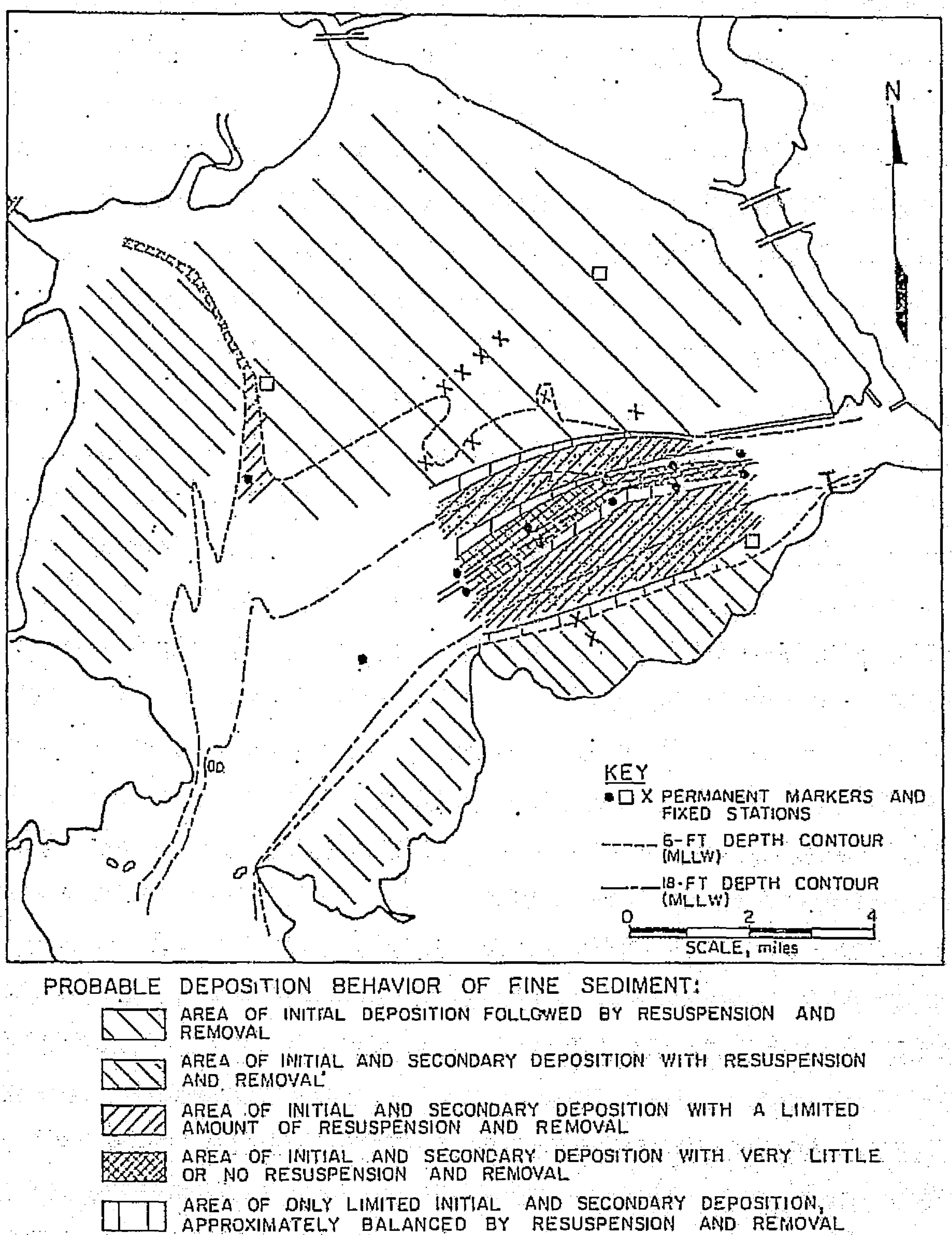


Figure 2-7. S190B San Francisco Bay.

This excellent (resolution 10 meters) color picture shows the detailed surface current structure of San Francisco Bay at 1141 on January 26, 1974. The spreading or hydraulic release of the waters entering San Pablo Bay and the Pacific Ocean are clearly observable during this high sediment discharge period. NASA, SL4, S-190B, 92-336, 26 Jan 74.



From: Klingeman and Kaufman, 1965.

Figure 2-8. Probable Deposition Pattern for Fine Sediment in San Pablo Bay.

Turbidity measurements in Carquinez Strait were collected during the Skylab overpass period in January 1974. These data, as shown on Figure 2-9, are plotted on a percentage of total light transmission through a ten centimeter water column. With knowledge of the inherent errors that result from using light transmission characteristics for determining suspended solids volume these curves are utilized for approximations of sediment distributions. (Volume determination errors result from differences in particle shape, platy vs. rounded shaped particles, calibration of transissometer and light source, etc.). The volume of suspended solids that are utilized in the following discussion resulted from applying the percentage of transmission to the graph in Figure 2-10 for Mare Island Strait. In the center channel the surface load was 250mg/l, a very high concentration of material during the flood runoff.

This magnitude of sediment transport in the center channel surface where maximum velocity and load carrying capability is to be expected. When compared to the Skylab imagery for the period it is noted that this was the area of peak reflectance and thus peak transport of fines.

In addition, the turbidity measurements at the disposal site (Figure 2-9) were constant from the surface down to the 10 meter depth. This indicated that this was not just a surface phenomena caused by a freshet. Complete mixing between the ocean and fresh water has apparently occurred by this point and the suspended solids are distributed through the water column. It should also be noted that the surface turbidity decreased during later collecting periods in February and March 1974. This was a result of a decrease in suspended solid volume as the rainy season ebbed in the Sierra Nevada and Great Valley source areas.

The S-190A density plots of the Bay that are shown in Figure 2-11, illustrate the sediment distribution characteristics during the Skylab 4 overpasses. Each plot was made by viewing the image transparency on the Data Color Densitometer (see Section 5). The distribution of densities were then transferred from the color plots to this figure for interpretation. In the unfiltered case the maximum reflectance was represented in the main channel of the Carquinez Strait. This was the area where the 250mg/l surface suspended solid concentration was measured. Toward the South Bay the expected decrease in load is noted. At the Golden Gate Bridge the surface suspended solids were estimated to be about 50mg/l. This estimate was based on both historical information for maximum discharge periods and the density differences noted on the density plots.

The filtered density plots on Figure 2-11 B, C and D were made for analysis of the spectral characteristics of the San Francisco Bay surface waters. One frame of S-190A color imagery was utilized for control so no film or developing characteristic differences would be entered into the results. On the densitometer only the filter over the viewing camera was changed. The results indicate that in the area of maximum sediment transport the peak spectral reflectance was about .55 microns. Distribution patterns for the 4900A, 5300A and 5900A narrow band ($\pm$100A) filters are shown. The 4900A band illustrates a lack of sensitivity. A large area in the density level contoured as level 1 (high sediment content) was present. Anticipated water penetration resulted in wide spread distributions of the initial density levels, subsurface as well as surface sediment being visible in the band.

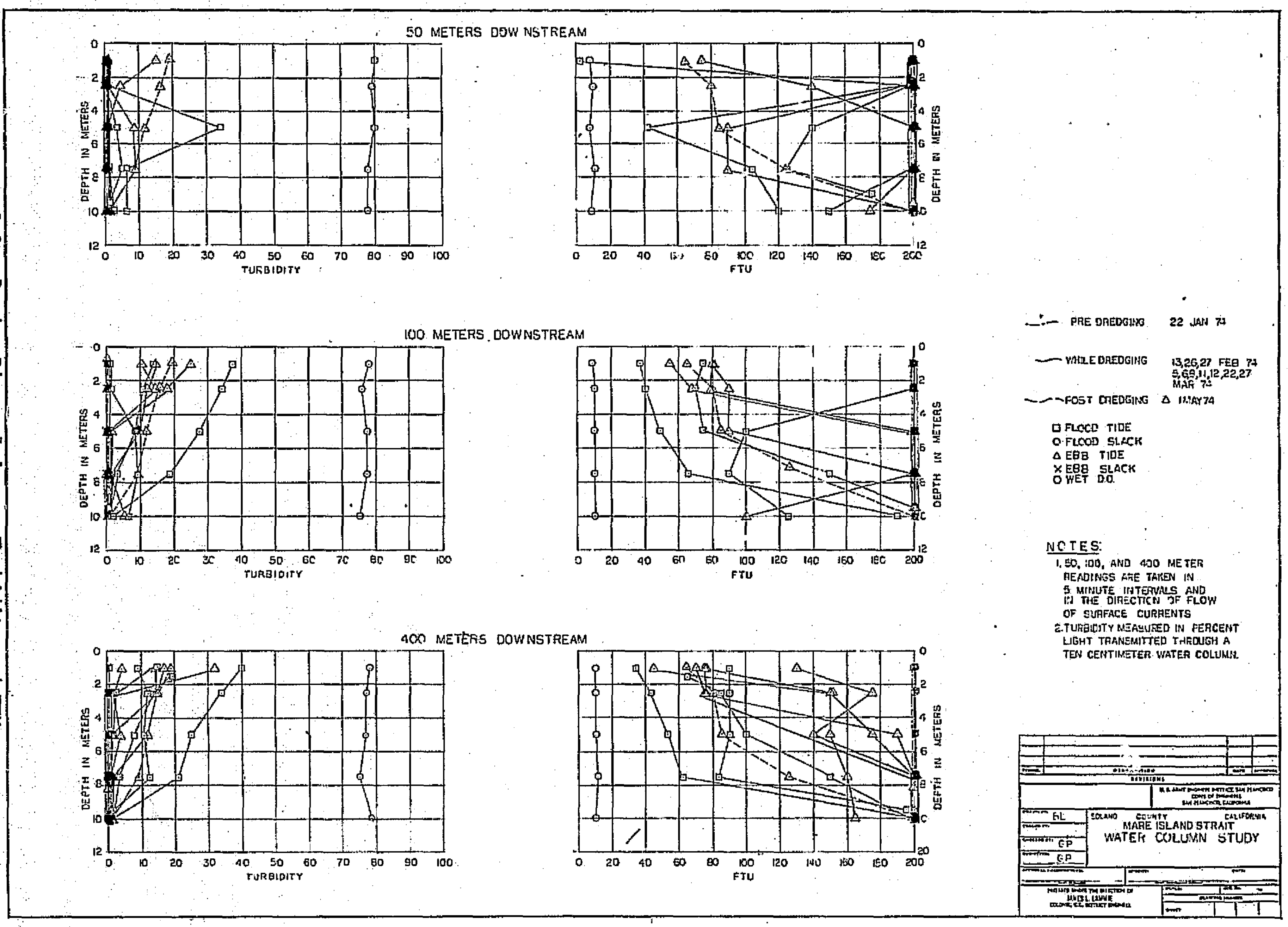


Figure 2-9. Dredge Disposal Area - Turbidity and FTU January through May 1974.

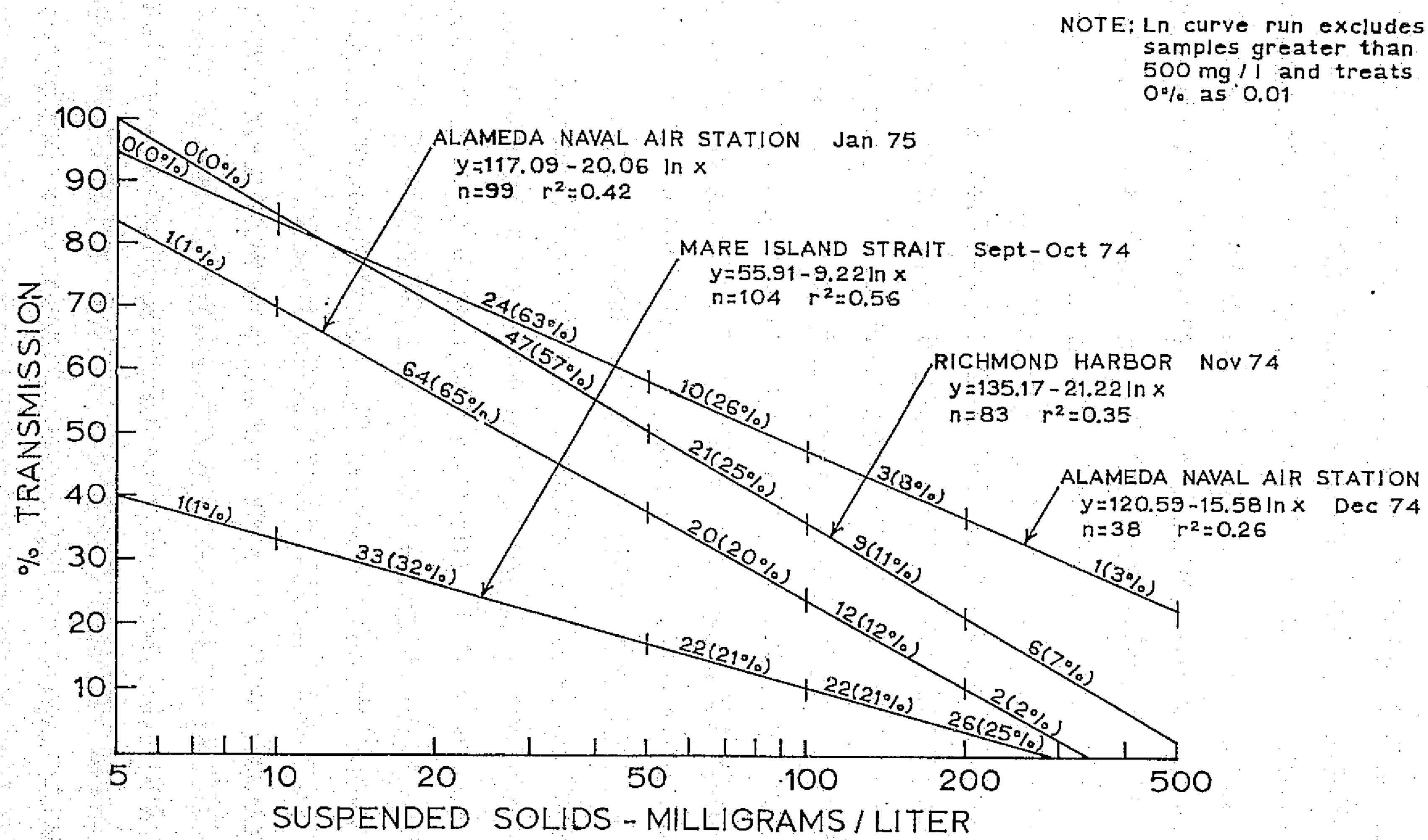


Figure 2-10. % Transmission vs Suspended Solids

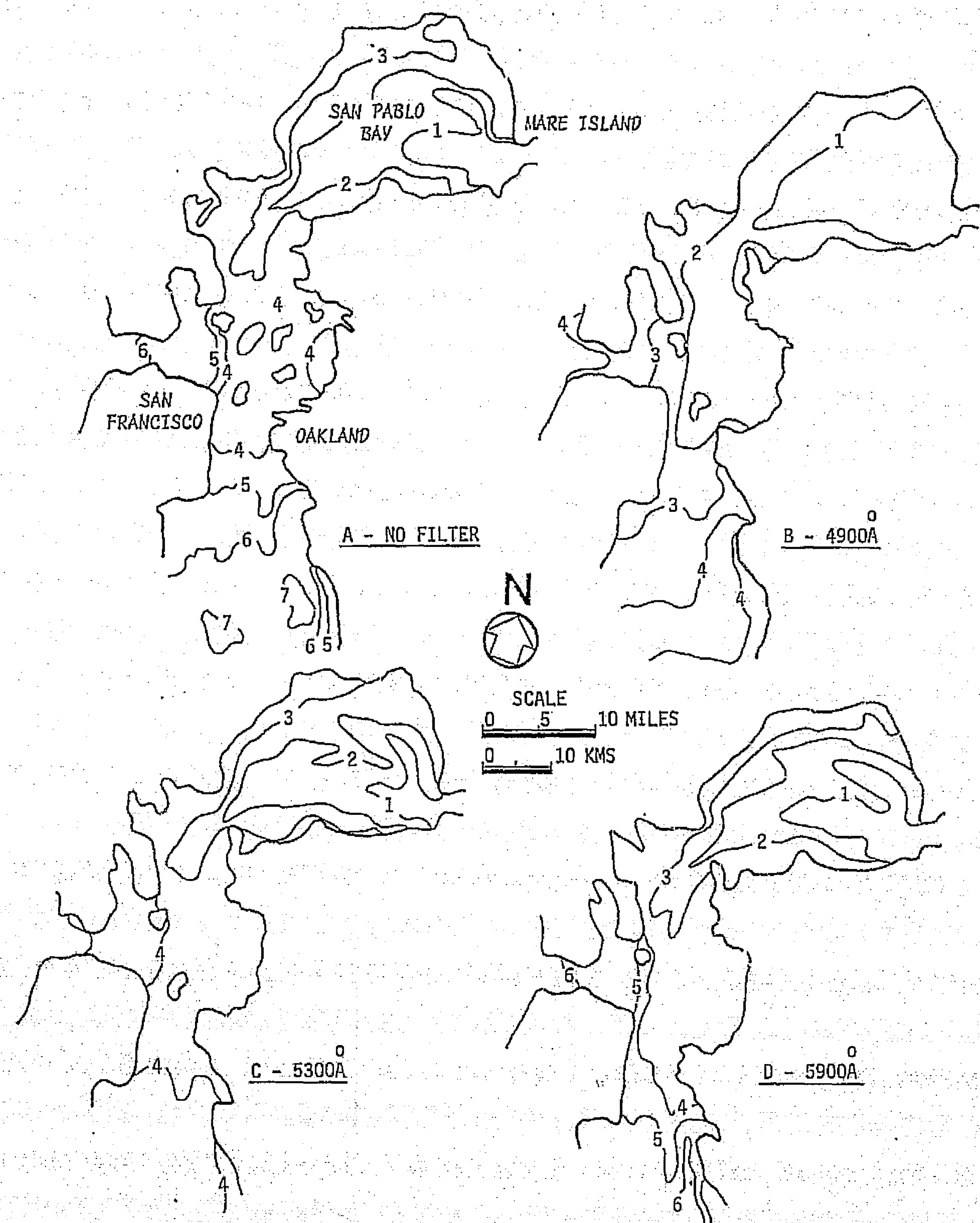


Figure 2-11. Density Plots of S-190A Color.
Plots B, C and D are filtered contours as indicated. Peak reflectance of suspended sediment was .55μm. Filters were ± 100Å. Contour intervals represent high (No. 1) to low (No. 6) reflectance. NASA, SL4, S-190A, 92-337, 26 Jan 74.

Plot 2-11C (5300A) approaches the spectral reflectance peak of sediments. An appreciable decrease in the size of level 1 density contours is evident and in addition, more levels of densities are appearing in the San Pablo Bay area. The contours from the high reflectance values generally follow the location of maximum sediment transport. As the spectral peak for the maximum suspended solid level was passed, as shown in Figure 2-11D, the aerial extent of the level 1 density was again increasing showing a decrease of sensitivity. The overall patterns illustrating sediment distribution closely correlate with the sediment distribution patterns indicated by in-situ measurements and computer processed imagery.

Of the methods evaluated to enhance Skylab imagery color separations proved the most useful in distinguishing clear and sediment laden waters. For the January 26, 1974 Skylab overpass a majority of information on the actual suspended sediment content was available. The comments below are mainly based on the analysis of that day's imagery (see Figure 2-12). During this period the water issuing through Carquinez Straits and out of the Russian River was heavily laden with suspended sediment. Comparisons of in-situ water sediment measurements to isodensity analysis of different Skylab color bands reveals that the .55 micron band shows the highest reflectance over the heaviest sediment loads in the images. Gradual dispersion and deposition takes place away from these areas of maximum sediment load, as mixing and loss of velocity occurs. Density analysis reveals where the sediment is moving and what forces are acting on it. The ability to detect water color is due to a peak reflectance occuring at longer wave lengths over the sediment laden water and at shorter wave lengths over the clear water.

The Skylab imagery as illustrated in Figure 2-12 gives an example of a normal color rendition and two color separations (bands) of the same scenes. As has been noted, if only one band were to be available, color photography on the High Resolution Color Film (SO 356) would be preferred. This preference is based on the wider useful spectral range of .4 to .7 microns and the ability of the human eye to discriminate the color differences in the picture. When making quantitative interpretations of sediment concentrations, however, the spectral separation resulting from the S-190A experiment are most useful. Both of the black and white bands illustrated in Figure 2-12 used SO 022 Pan X film but with different filters. The shorter band, .5 - .6 microns, shows a maximum suspended sediment distribution plus maximum water penetration analysis. A problem which occurs with this band, however, is that it is impossible to determine whether the sediment is in the surface water layers or distributed into subsurface water. A further possibility is a somewhat even distribution throughout the water column. If this band alone were used, of course, no separation could be made. When the shorter band is interpreted in combination with the next longer band (.6 - .7 micron) however, it is possible to determine which sediment is near surface. This red band, (.6 - .7 microns) detects only surface and near surface suspended particles. A photo interpretation or densitometer comparison between these two bands provides a comparison of the suspended sediment vertical distribution. Some of the determining factors in the precise measurement of light penetration necessary for quantification include: sun elevation, cameras and film, transmissometer characteristics and suspended particle shape and size characteristics. The physical characteristics of the water and included material were determined mainly from the previous days data collection plus prior experience. In studying the San Francisco Bay area during Landsat, aircraft overflights and numerous in-situ Bay studies were used.

It should be noted that the precision to which analysis is possible is partially determined by the width of the spectral bands. If the spectral ranges were split at .05 microns rather than the Skylab .10 microns, a great deal of additional information would be available. This, of course, would have to be coordinated with other disciplines using the information, but narrower bands would be welcome in the oceanographic coastal studies area.

2.4 ANALYSIS OF DREDGE SEDIMENT DISCHARGE

The movement and eventual distribution of both natural and dredged sediment in San Francisco Bay is of major importance to the commerce of the Bay area. San Francisco Bay represents the source of a myriad of water activities including recreation, shipping, industrial facilities, transportation and waste disposal. The U.S. Army Corps of Engineers with responsiblity for the water-way clearance and navigation facilities, has carried out a number of pertinent studies of the Bay. Several recent studies on dredging and dredge sediment distribution lend themselves extensively to the study of the Bay sediment transport and current activity. The study of the movement of dredged and natural sediments in Carquinez Strait was underway during the Skylab 4 overpass in January 1974. Preliminary results from this sediment study were used as the basis for the Skylab imagery interpretation.

Maintenance of deepwater shipping channels in San Francisco Bay and its various estuaries required periodic dredging. Disposal of dredged material has for many years been accomplished by disposal at designated sites. The ultimate fate of the material was not precisely known, but as the disposal areas were all in scoured channels, natural current moved the wastes to areas of wide dispersion.

San Francisco Bay sediment movement attributable to dredging operations is only a minor fraction of net sediment movement brought about by winds, tidal currents, fresh water flows, and similar natural processes. In recent years, concern has been expressed about possible detrimental effects of disposal of dredged material on benthic organisms in the bay ecosystem. More recently, additional concern has been focused on possible effects of water quality as dredged sediments are released.

The U.S. Army Corps of Engineers, San Francisco District, performs maintenance dredging in Mare Island Strait, which comprises the lower end of the Napa River. Discharge of the dredged material takes place in designated disposal area south of Mare Island near the westerly end of Carquinez Strait (see Figure 2-6). The material is comprised of silts and clays from the Bay system and sediments and debris from the Napa River. Previous studies showed that these sediments are somewhat polluted by current criteria. Pollution sources included the urban drainage of the City of Vallejo and the Mare Island Naval Shipyard. Until recently, industrial wastes were discharged without treatment from the shipyard into the Bay.

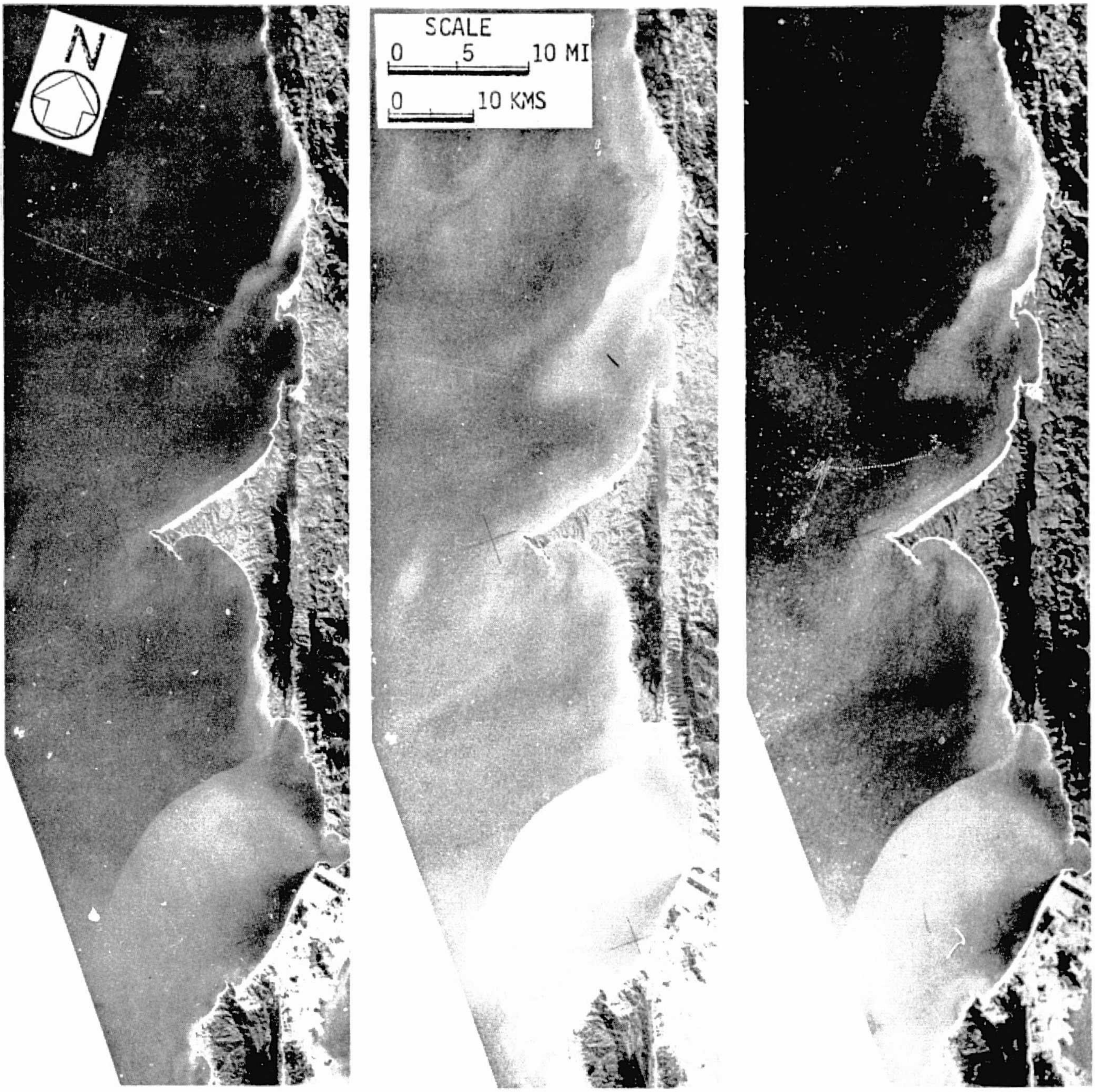
During the Skylab study period, an iridium tracer was added to dredged sediments which were then dumped about 3.2 km southwest of Mare Island Strait. The Skylab 4 experiments S-190A and B and S-192 were utilized in collecting extensive imagery of the area in January 1974. The result is the ability to use the sediment color and volume characteristics to locate transport and distribution patterns. A close correlation was found between the Skylab imagery and distribution of transported sediment within San Pablo Bay. The Corps developed a computer plot to show the location of dredged materials from the January and February deposition drops (Sustar, 1975). Figures 2-13 to 2-16 for the months of May, June and July 1974 show the dredged material distributions as determined from analyzing samples of the tracer identified material. The top layer (top one inch) of deposited sediments from 82 sites in San Pablo Bay were used in making these plots. The tracing of the dredged materials from Mare Island Strait gives a quantitative picture of the dynamic currents within the Bay. It must be realized that the samples and results used in this interpretation were not in a static state. Each monthly plot represents at least two weeks of data collection. This time consuming method as opposed to the instantaneous Skylab view of the area illustrates the advantage of utilizing EREP coverage for sediment transport analysis.

The field samples were analysed by the Neutron Activiation Methods (see Sustar, 1975 for details) by the U.S. Army Explosive Excavation Research Lab of the Waterways Experiment Station. For the purpose of this investigation the plots of the bay bottom surface samples only were utilized. This is because the satellite imagery views water surface features only. It is believed that the bottom's surface samples will be most closely correlated with deposition of the water surface features as detected on the Skylab imagery. The plotted data was then utilized in the computer plots, Figures 2-14 to 2-16 to illustrate the distribution of the dredged material in San Pablo Bay. The first plot was for May, three months after disposal. The second was for June, four months after disposal and the third for July, five months after disposal.

In analyzing the dredge disposal study plots it becomes apparent that a constantly shifting bottom environment was represented. The fact that high percentage (40% to 80%) localities of dredge materials were detectable months after the drop is significant in analyzing the ecosystem and the dynamic forces in play. These locations have been found 13 to 16 kilometers from the original drop sites. At 16 kilometers (San Pablo Strait) the sampling grid ended. The movement of bottom samples are directly related to the surface currents and tides which are significant when interpreting Skylab imagery. It should be recognized that the water over the majority of San Pablo Bay is shallow. Much is less than 4 meters deep. Patterns of sediment transport that show up on the Skylab pictures are indicative of the sedimentation patterns shown by the distribution plots. The color picture of the area (Figure 2-7) taken January 26, 1974 illustrates the hydraulic release pattern as the Sacramento-San Joaquin River water enters San Pablo Bay at the Carquinez Strait (the location of the dredge sediment drops). Besides the continuation of the sediment-laden water down the main channel a jetting effect occurs. The result is a three-pronged pattern with the two outer prongs moving southwest along the coast toward Pinole Point and northwest into the area of the Petaluma River mouth. The central prong follows the central channel. The southwest prong of sediment-laden water moves along the crescent-shaped coast and then rejoins the main channel off Pinole Point. This is the locale of a high concentration of dredged material from the May and July dredge disposal plots. In the June plot the major buildup was in the center of the Bay north of Pinole Point. This is probably the result of the prevailing westerly winds which cause considerable wave resuspension during the summer. The location of the maximum dredge sediment concentration indicates that a shift to the east occurred after the May samples were collected.

The northwestern prong of this feature appears to move the sediment-laden waters into the north Bay and across shallows. These materials don't appear to rejoin the main channel prong but deposit in the shallows between Mare Island and Pt. San Pedro. The plots confirm this pattern. Heavy concentrations of dredge tracer material were found in this area in the months of May, June and July 1974. The heaviest concentration moved across the Bay to the vicinity of the Petaluma River mouth by July. It is apparent from analyzing the sediment distribution plots that these movements are directly related to the surface patterns that are visible on the Skylab pictures.

For an operations application of correlating satellite imaged surface patterns to sediment deposition in bays and estuaries, more information will be required than that which was available for this limited study. Repetitive coverage from a stationary satellite capable of resolving and vectoring surface currents in the range of 0.2 to 3.0 meters per second should be obtained over the various tidal, river flow, meteorological and temporal cycles that affect sediment deposition. Statistical correlation of imagery density plots with cyclic phenomena and field survey data would then produce a model suitable for processing imagery into sediment deposition and dredging requirements forecast. The minimum ground field data that would be required to initiate such a model development program would consist of sediment quantification and properties, salinity profiles, current profiles, and spectral attenuation profiles.



FRAME 77-71
(.6-.7 microns)

FRAME 78-71
(.5-.6 microns)

FRAME 76-71
(Color .4-.7 microns)

Figure 2-12 Coastal Processes Color Separation

For differentiating coastal processes Skylab imagery provides an advantage through the use of various black and white and color photographic bands. The .5 - .6 micron band displays detailed information including the effects of water penetration. In the .6 - .7 micron frame surface detail is presented without interference from subsurface sediments. Color photography proved more useful when performing a single picture interpretation. NASA SL4 S190A 26 JAN 74.

Figure 2-13. San Pablo Bay Suspended Sediment vs Dredge Disposal Plot

May dredge disposal % plot (Figure 2-14) overlain by January 26, 1974 Skylab suspended sediment distribution. Correlation between sediment transport pattern and areas of high percentage of dredged material is noted.

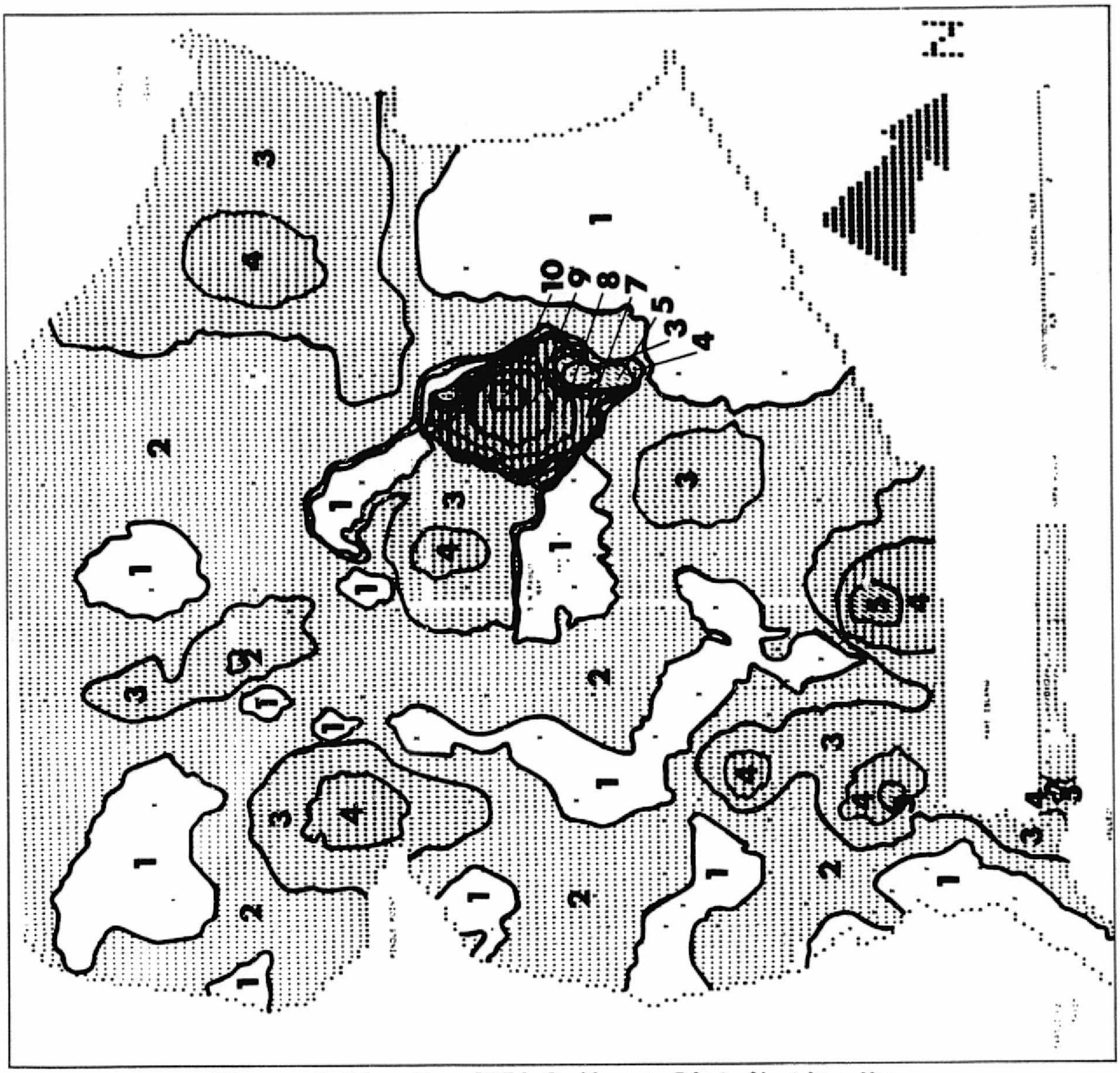


Figure 2-14. May 1974 Sediment Distribution Map.
Sample Station indicated by X.

EXPLANATION

Displayed is the % Dredge Material Observed in Sample - Top Layer.

Level	Value	Frequency
1	0-.5	42
2	.5-3.0	33
3	2.0-4.0	12
4	4.0-6.0	4
5	6.0-8.0	4
6	8.0-10.0	1
7	10.0-20.0	0
8	20.0-40.0	0
9	40.0-80.0	0
10	80.0-100.0	1

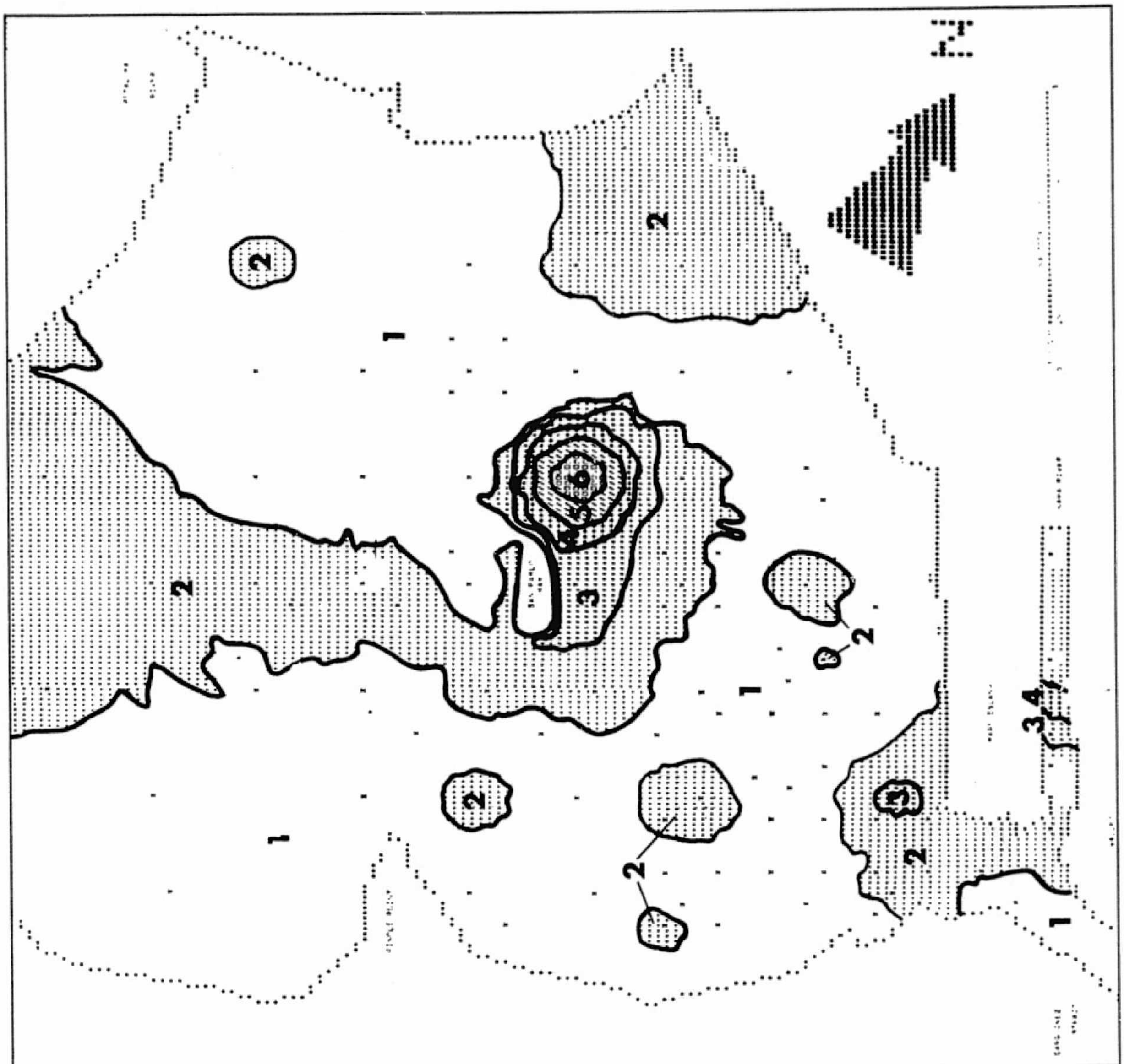


Figure 2-15 June 1974 Sediment Distribution Map. Sampling Station indicated by X.

EXPLANATION

Displayed is the % Dredge Material Observed in Sample - Top Layer.

Level	Value	Frequency
1	0-.5	64
2	.5-2.0	24
3	2.0-4.0	6
4	4.0-6.0	1
5	6.0-8.0	0
6	8.0-10.0	1

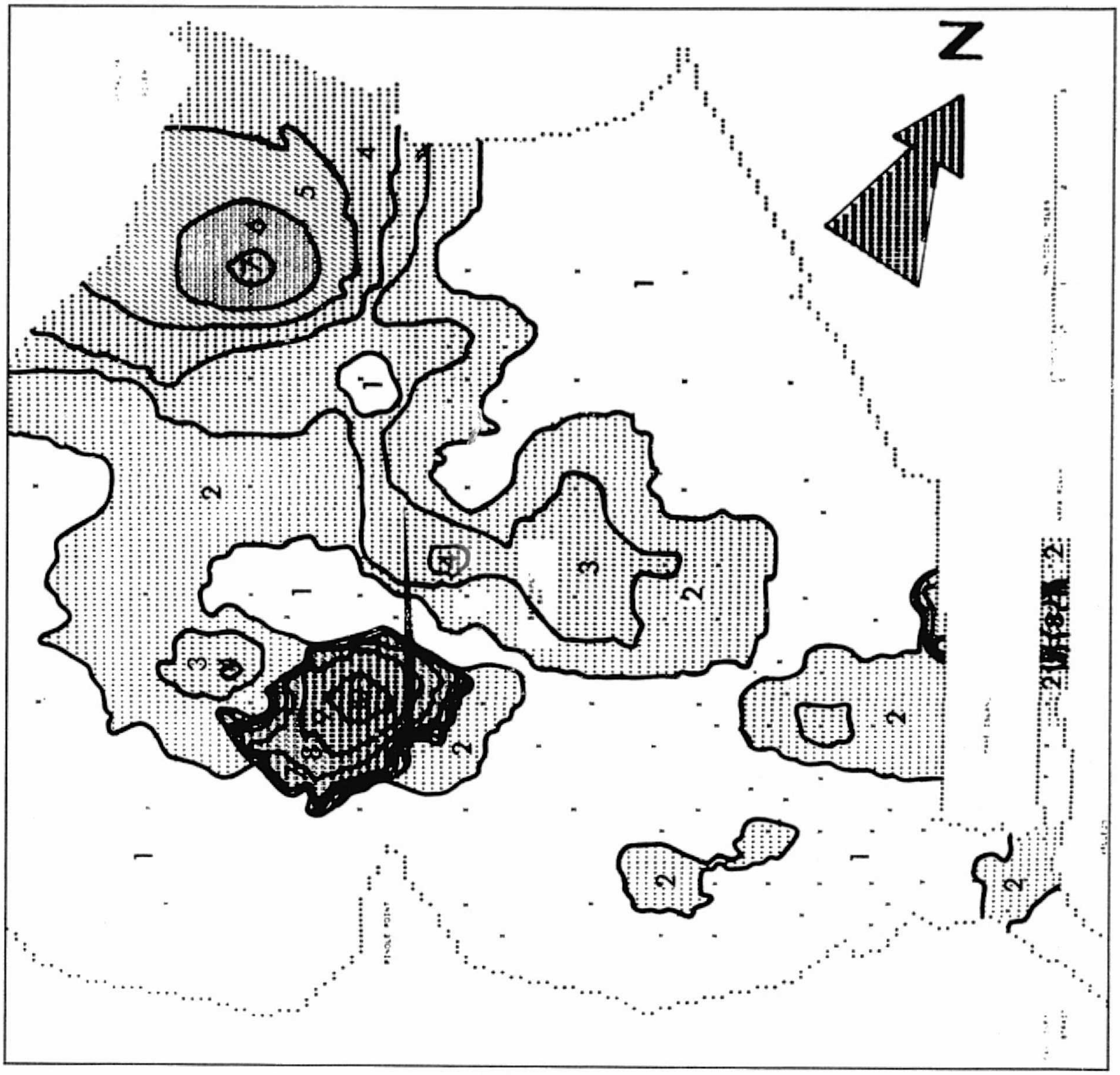


Figure 2-16. July 1974 Sediment Distribution Map.
Sample Station indicated by X.

EXPLANATION

Displayed in the % Dredge Material Observed in Sample - Top Layer

Level	Value	Frequency
1	0-.5	65
2	.5-2.0	20
3	2.0-4.0	7
4	4.0-6.0	3
5	6.0-8.0	0
6	8.0-10.0	0
7	10.0-20.0	1
8	20.0-40.0	1
9	40.0-80.0	0
10	80.0-100.0	1

3.0 IMAGE PROCESSING FROM S-192 TAPE

The S-192 tapes from the multispectral scanner were reformatted and processed to make color enhancements (Figure 1-1). Color composites include the north part of San Francisco Bay and the coastal area near the Russian River and Bodega Bay. These two frames were picked for illustrating the utilization of the S-192 imagery because of the interest in coastal processes at each of the sites. Although many different descriptions and enhancements of San Pablo Bay are included in this report the features visible in Figure 1-1 are unique in detail. As the waters from the Sacramento-San Joaquin Rivers enter the Bay from the lower right they are hydraulically released and spread as represented by the white and yellow on green in this enhancement. The jetting effect to the right (top) contains the largest suspended sediment load. As this material moves into the shoals in the north Bay (near the 3 sets of dropped scan lines) it is turned southward toward the San Pablo Straits and the south Bay. Just off Pinole Point (bottom center) is an area of low surface suspended sediment concentration. This corresponds to the area classified as one of only limited initial and secondary deposition approximately balanced by resuspension and removal (see Figure 2-8).

When this enhancement of San Pablo Bay is compared with the sediment distribution map for May 1974 (Figure 2-13) one notes a close correlation. Areas on the enhancement that appear to be receiving the greatest amounts of surface sediment closely correspond to the area of maximum deposit on the May plot. The maximum concentration is just to the right of the entrance channel at Carquinez Strait where the maximum sediment concentration occurs. The area of Pinole Point mentioned in the last paragraph is the site of minor sediment concentration. This correlation of surface transport and depositional patterns, although not exact, seems to present an excellent means of predicting sediment movements. On this enhancement the concentration at the Carquinez Strait is known to be approximately 250mg/l as described in Section 2.

The second enhancement in Figure 1-1 shows the Russian River sediment discharge on January 26, 1974. The hook shaped feature toward the bottom center of the picture is Bodega Bay. The suspended solids shown in white and yellow against the green water background are flowing southward and are slightly disrupted off Bodega Bay where a hump appears in the boundary between the sediment laden and clear waters. The speckled pattern in the clear water is the result of sun glint off the southeasterly moving wave trains. It should also be noted that an upwelling was plotted just southwest of Bodega Bay on this date. The effect of this upwelling is causing the discharge pattern to stay offshore and not move directly down coast in this longshore current.

3.1 PROCESSING APPROACH

Information used for the color composites and pictures that follow is contained within a Skylab S-192 image and stored on digital tape as discrete 8-bit encoded pixels. Each pixel has a value between 0 and 255 called a digital number (DN). An entire image consists of numerous rows of pixels that form scan lines. Each line contains either 2480 or 1240 picture elements (pixels) dependent on the specific spectral band. In addition, a total of 7 geographically registered spectral bands were available to completely describe a scene (Table 3.1). This multispectral aspect permits the application of numerous processing techniques to enhance and extract a maximum of information. Such techniques, in part, include classification, entire band ratioing, subtraction, and additive processing. Alternate approaches pursuant to enhancing the visibility of information within a discrete S-192 image or spectral band also exhibited potential. Signal thresholding, contrast stretching, and density slicing represent this second class of processing approaches.

Previous studies of coastal processes from space imagery (Pirie and Steller, 1974) indicated that spectral signatures of related features were predominantly contained within the .45 - .64 micron portion of the spectrum. This range correlates directly to Skylab bands 2-5 of which only one band was available for processing. This situation resulted in limited application of multispectral processing techniques. Normal procedures would dictate that candidate processing algorithms be applied and the resulting enhanced imagery evaluated. This evaluation established a basis for updating specific parameters within an algorithm to optimize its effects on the image. The time frame prevented the implementation of this iterative approach. Thus, examples and evaluation contained within this report are a result of fundamental first pass processing. These enhanced imagery provided the basis for evaluating the merit of those techniques applied to Skylab data.

3.2 PROCESSING METHODOLOGY

Figure 3-1 illustrates the processing methodology applied to Skylab digital tapes. The Jet Propulsion Laboratory (JPL), Pasadena, supplied support towards the establishment and implementation of this procedure. In addition, the GE-100 Image Analysis System was utilized for performing image enhancement of the Skylab digital data.

The data tapes were first converted from the NASA S-192 universal tape format to the VICAR format; this format being the one universally used throughout JPL's entire complement of image processing software and hardware. The available processing techniques and logical flow sequences are explained in detail by Billingsley, 1974. The following discussion is a description of those processors and procedures pertinent to this study. To establish a basic understanding of the processing approach the following description is given.

Table 3.1. Listing of Planned S-192 Spectral Bands

Band	Description	Range (μm)	Availability*
1	Violet	.41- .46	
2	Violet-Blue	.46- .51	
3	Blue-Green	.52- .56	
4	Green-Yellow	.56- .61	X
5	Orange-Red	.62- .67	
6	Red	.68- .76	X
7	Infrared	.78- .88	X
8	Infrared	.98-1.08	X
9	Infrared	1.08-1.19	X
10	Infrared	1.20-1.30	
11	Infrared	1.55-1.75	X
12	Infrared	2.10-2.35	
13	Thermal Infrared	10. 2-12. 5	X

* Data supplied for processing in Universal Tape Format.

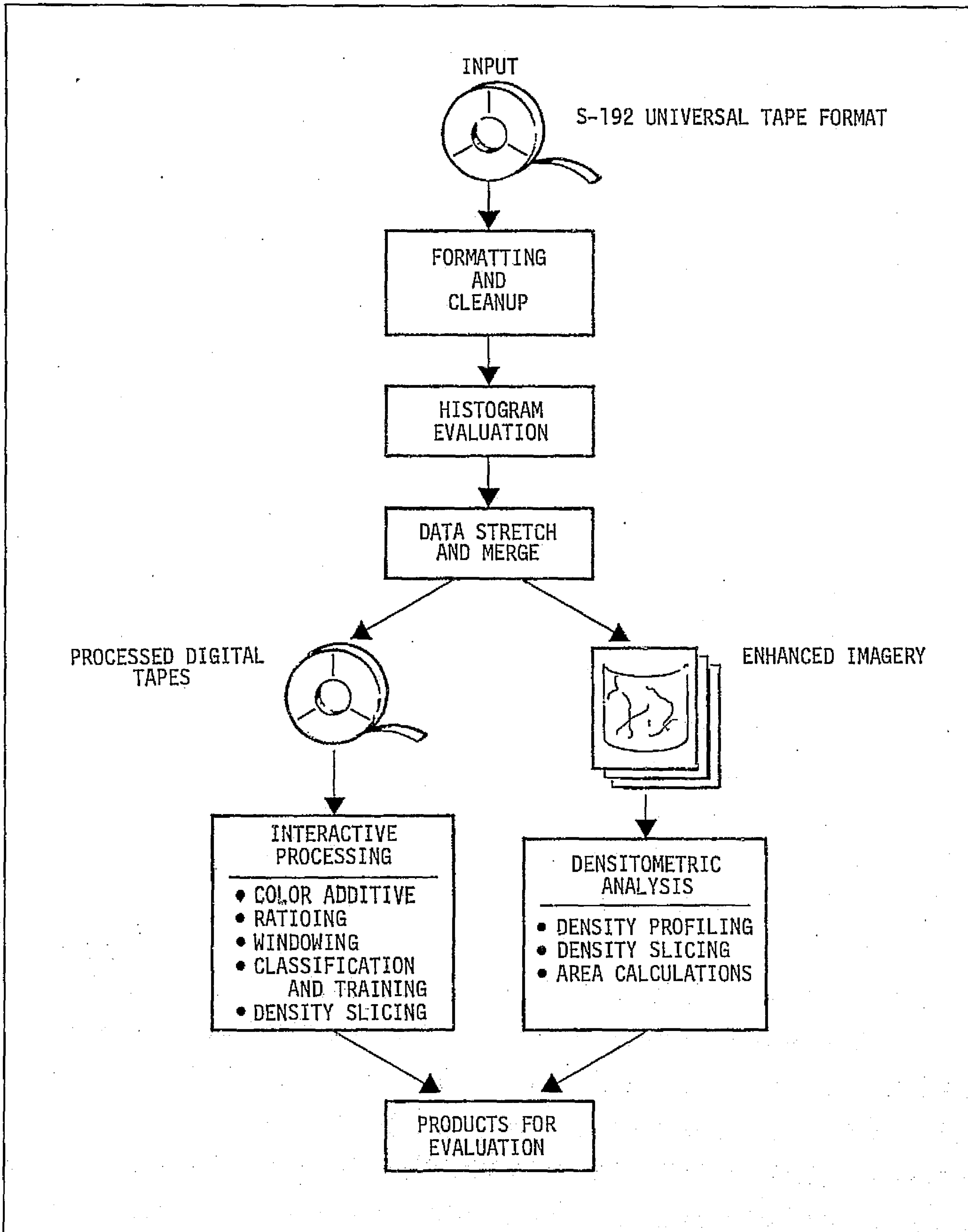


Figure 3-1. Processing Flow Diagram

3.2.1 Geometric Rectification

After attaining the VICAR format, one can proceed logically to the geometric distortion aspect of the data processing capability. This process, although desirable for producing a corrected produce, is inherently mathematically complex and once performed establishes no new information. Considering the available data processing time frame and additional cost, it was decided that the emphasis should be placed on those processors more tailored to the enhancement and extraction of information.

3.2.2 Contrast Stretching

The S-192 Earth Resources Experiment Package (EREP) was designed to accomodate a wide range of scene brightness. However, the range of digital numbers recorded on tape was limited to 255 discrete levels. This range is compatible with JPL's film recording hardware and allows for maximum scene contract in an output image if the input signals cover the entire range. This condition did not exist for all original data sets and is apparent if one considers different scenes or different spectral channels of the same scene. It was desired that all output products display the maximum contrast, thereby enhancing the visibility of information contained within that image. To insure this condition, a process called ASTRTCH2 was used. The entire set of digital numbers contained within an image were used to generate a display histogram as shown at the bottom of Figure 3-2. Although graphically shown in the figure, it represents a statistical basis for the processor to perform a mapping or stretch of the original data set into the enhanced set. A film image then produced from this processed tape is insured to contain the maximum contrast range.

Examination of the Figures 3-2 to 3-6 shows that the amplitude assigned to each digital number was a normalized value representing the number of pixels for a digital number, or in fact it represents a density distribution of the image. In addition, it includes a mean and standard distribution. Based on this distribution, a lower and upper digital number is determined which truncates the lower and upper 3% of the distribution curve. These values then bracket the digital number range to be mapped or stretched into the new 0-255 signal range. The stretch performed can be linear or nonlinear (nonlinear stretches being exponential, logrithmic, roots, etc.). The linear stretch was used exclusively for this study. The result was an increase in contrast. The data tape produced was used to generate hardcopy images shown in Figures 3-2 to 3-6 and also served as input to the GE-100 system.

3.2.3 Channel Merging

The basic number of pixels per scan is 1240 for each spectral band. This number is a result of the sampling rate used during the data acquisition phase. Actually, two different sampling rates were employed when producing the raw REP 28-track data tape. The second rate was twice that of the first; thus resulting in 2480 samples per scan. Bands 1, 2, 8, 9 and 13 were sampled at the lower rate, while bands 3, 4, 5, 6, 7, 11, 12 and 13 were sampled at the higher one. (Note that band 13 was sampled at both rates.) A total of 22 channels were required for recording those bands sampled at the high rate required two channels for recording with the data separated by odd and even pixels.

To achieve a consistent number of samples per scan a program called SKYMRG was used (see Figures 3-2 and 3-3). Adjacent pixels, one even, the other odd, were read in from the two channels, merged or averaged to attain a single pixel, and then output as a representative value for that band. The result was 1240 pixels/scan produced from the 2480 picture elements available from both channels.

Two scenes were processed from tape during this study. Each scene was contained on three 8-track 900 BPI tapes. Remembering that data produced by the S-192 scan is a continuous strip 72.3 km wide (116.4 miles) along the orbit, the number of scan lines per scene is a variable. Approximately 600 lines of data are contained on each NASA tape. Once merged and joined the two scene produced from the available three tapes contained about 1500 lines of data. Four spectral bands for each scene were processed and reformatted. Hardcopy imagery of these tapes were produced, as shown in this report. The tape also served as input data to the GE-100 Image Analysis System.

3.2.4 Interactive Image Analysis

To facilitate the implementation and evaluation of most of the image enhancement technique, an interactive real time approach was pursued. The GE Image-100 provided this capability. The resultant tapes produced from the ASTRTCH2 and SKYMRG programs were in a format directly compatible for input to this system. A total of four bands can be stored within the system for processing. Thus, it represents a 4-channel analysis system. Bands 4, 6, 7 and 13 were used. Additionally, hardware limitations dictated that a maximum of 512 pixels x 512 lines of data be entered into each channel. Software was supplies so that an array of pixels could be extracted from any area within a scene.

A high-quality 525-line, 30 frame/second, 19-inch color CRT provides the system with a color or black and white display. Discrete bands, combinations of bands, or images resulting from multispectral, as well as single band enhancement techniques can be viewed and evaluated. Push button controls allow the user to assign and/or mix colors into the viewed display. Independent brightness and contrast controls for each primary color are provided to optimize the output image.

Color composites (see Figure 1-1) were generated by combining three of the availble four bands on the display monitor. Each band assigned and displayed as a different color. Various combinations were viewed and the resulting images evaluated. A ratioing technique was also applied by dividing two spectral images pixel by pixel. Variations in the slopes of the spectral reflectance curves would result in an enhancement of sediment transport. The results from this procedure showed little improvement to the visibility of these features. This can be attributed to the limited availability of spectral bands and the noisy quality of band 13 data. Pixel by pixel subtraction was also judged limited in utility for this study.

An alternate approach was also attempted. A cursor was positioned over areas of high sediment content. Internal algorithms automatically sampled data values resident to the selected local and established the decision criteria necessary to classify the feature sampled. This proce'ure can be performed on up to nine features or areas within a scene. The output display then shows these classes as unique colors for interpretation. The results again were limited in value for this project because of the bands available. These approaches required more spectral bands containing or bracketing the spectral signatures of offshore targets.

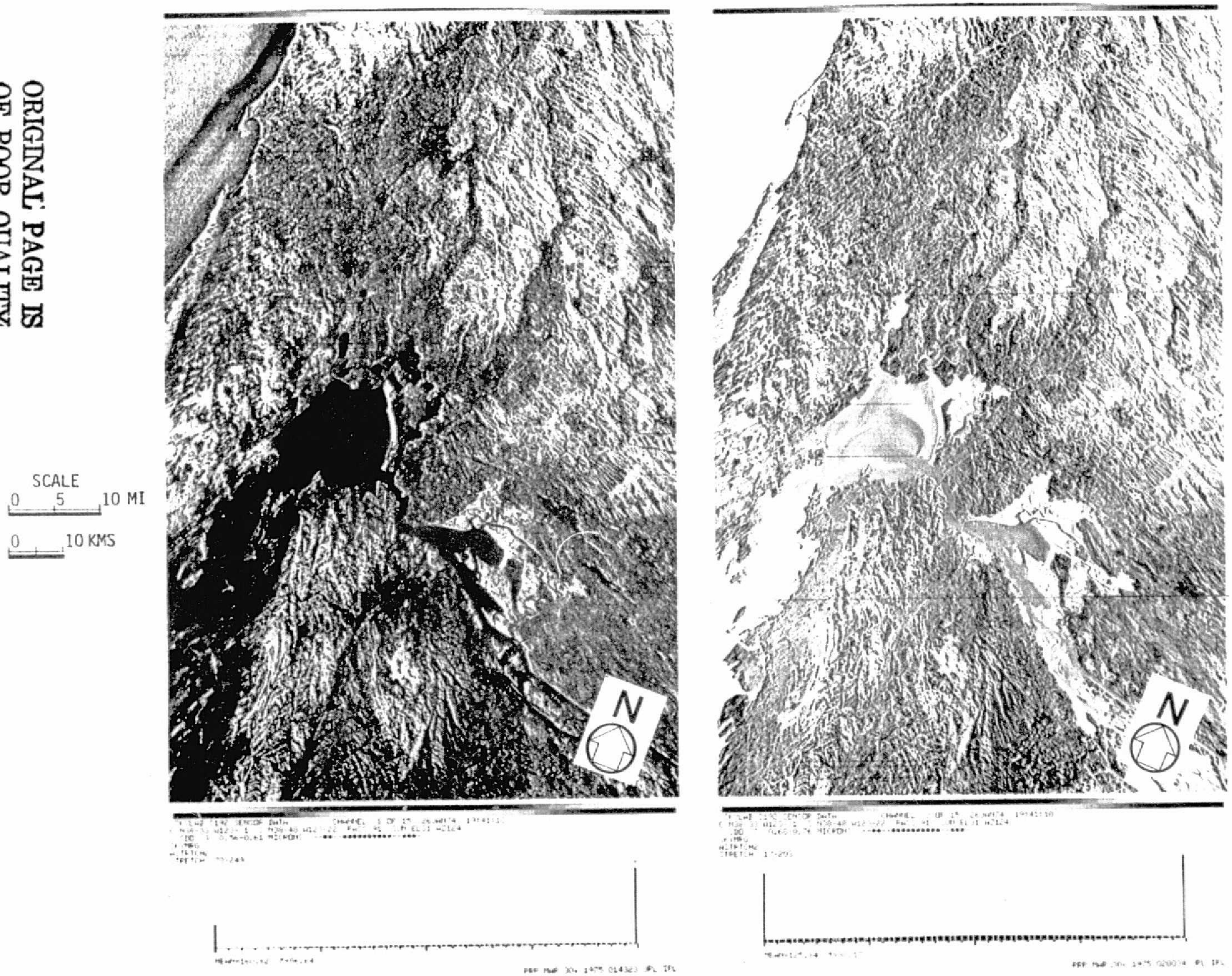
Figures 3-2 and 3-3 San Francisco Bay S-192, SKYLAB-4

These four unrectified negative images of the San Francisco Bay area illustrate the information available on S-192 playbacks. The negative images are presented because of there ability to discriminate subtle features in surface waters. Annotations are described in Figure 3-4. These images were merged (adjacent pixels averaged) as a result of a computer program which combines adjacent S-192 channels (indicated by the code work SKYMRG in the annotation). The grid marks along the sides of the image represent five scan lines per tick. Along the top and bottom of the image the ticks each represent 5 samples. There are 2140 samples per line. One sample on one scan line is a pixel or resolution unit. A pixel is a geometric shape 79 meters (260 feet) in the scan direction (side to side) and 88 meters (289 feet) in the flight direction (toward the bottom). See MSC-05528, 1974 for details.

The large volume of suspended sediments discharging into San Francisco Bay during this January 26, 1974 fly-over is illustrated in detail. In band 4, the spectral response of these materials cause such high reflectance (brightness levels) that details are obscured. It must be remembered that this is a negative image; thus, black represents high reflectance levels and white, low levels. The black levels in the Bay are the result of the large volume of suspended sediment reflecting in or near the spectral peak of band 4 combined with the relatively large foot print (pixel) of the scanner. In the upper left hand corner of this frame the signal from the Russian River discharge is seen moving southward as the result of the California Current (see also Figure 1-1).

In bands 6 and 7 the darker shades of gray in the Bay represent the areas of the higher volumes of surface suspended sediment. The hydraulic release affect is seen where the Sacramento River waters enter the north Bay. As the waters move toward the south, dispersion and settling causes a decrease in the surface sediments. Various complex current patterns are also observable. On band 6 note several dropped scan lines which cause the black lines running from side to side in the image.

Band 13 is the infrared thermal band that should show numerous water surface temperature differences. The only visible difference is at the point where the Sacramanto River waters enter the north Bay. This image shows only this one area of temperature change which indicates a possible lack of sensor sensitivity. It is probably also the result of reducing the 255 counts from the sensor to 64 density levels, thus suppressing differences below four counts. Where the Russian River discharges into the Pacific Ocean a definite thermal gradiant would be expected but none can be detected in this set of computerized images.



BAND 4

BAND 6

Figure 3-2. San Francisco Bay
S-192 Band 4 (green-yellow) and Band 6 (red) negative imagery.
NASA, SL4, S192, 19:41:10, 26 Jan 74.

SCALE
0 5 10 MI
0 10 KMS

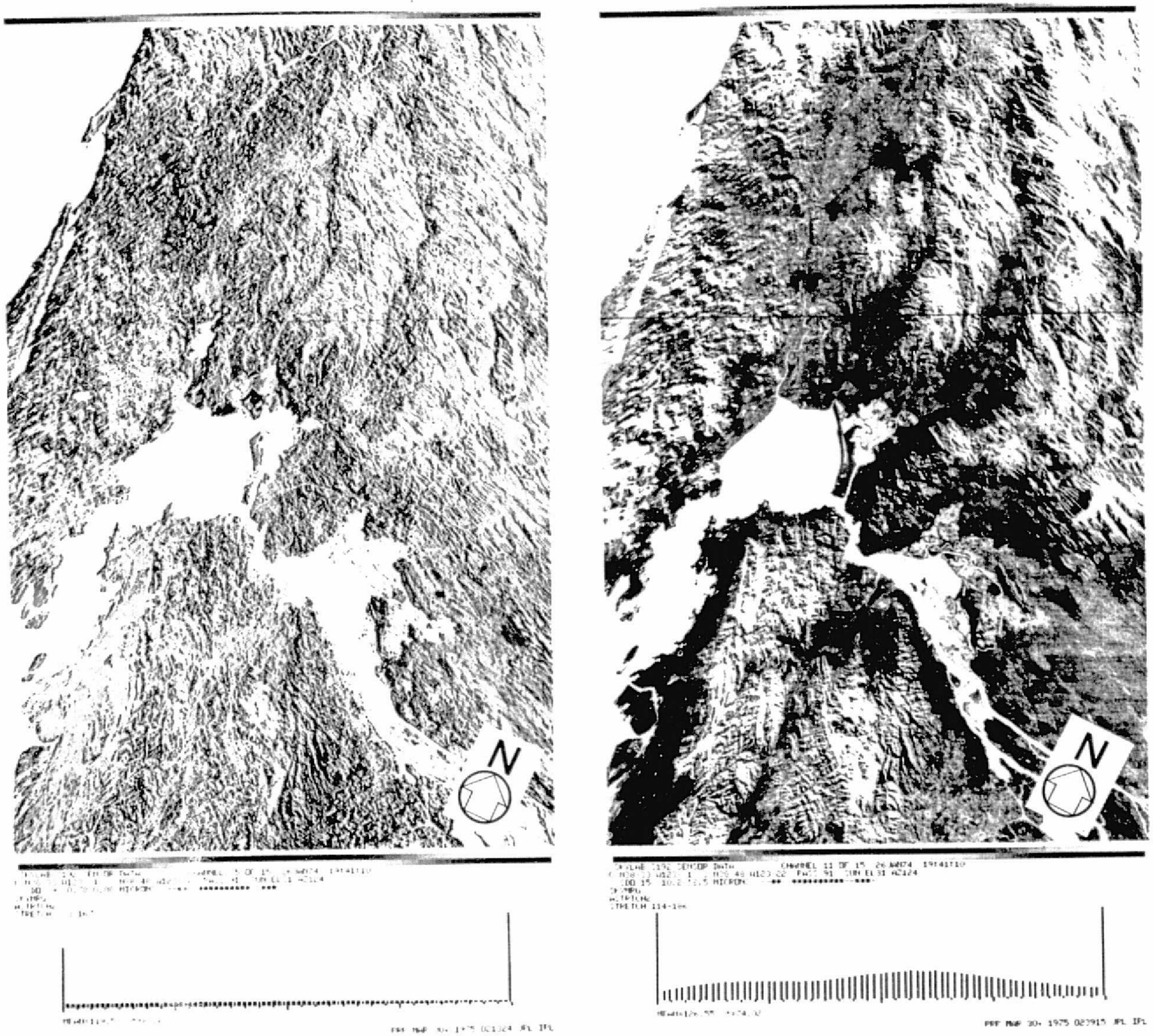


Figure 3-3. San Francisco Bay
S-192 Band 7 (infrared) and Band 13 (thermal infrared) negative imagery.
NASA, SL4, S192, 19:41:10, 26 Jan 74.

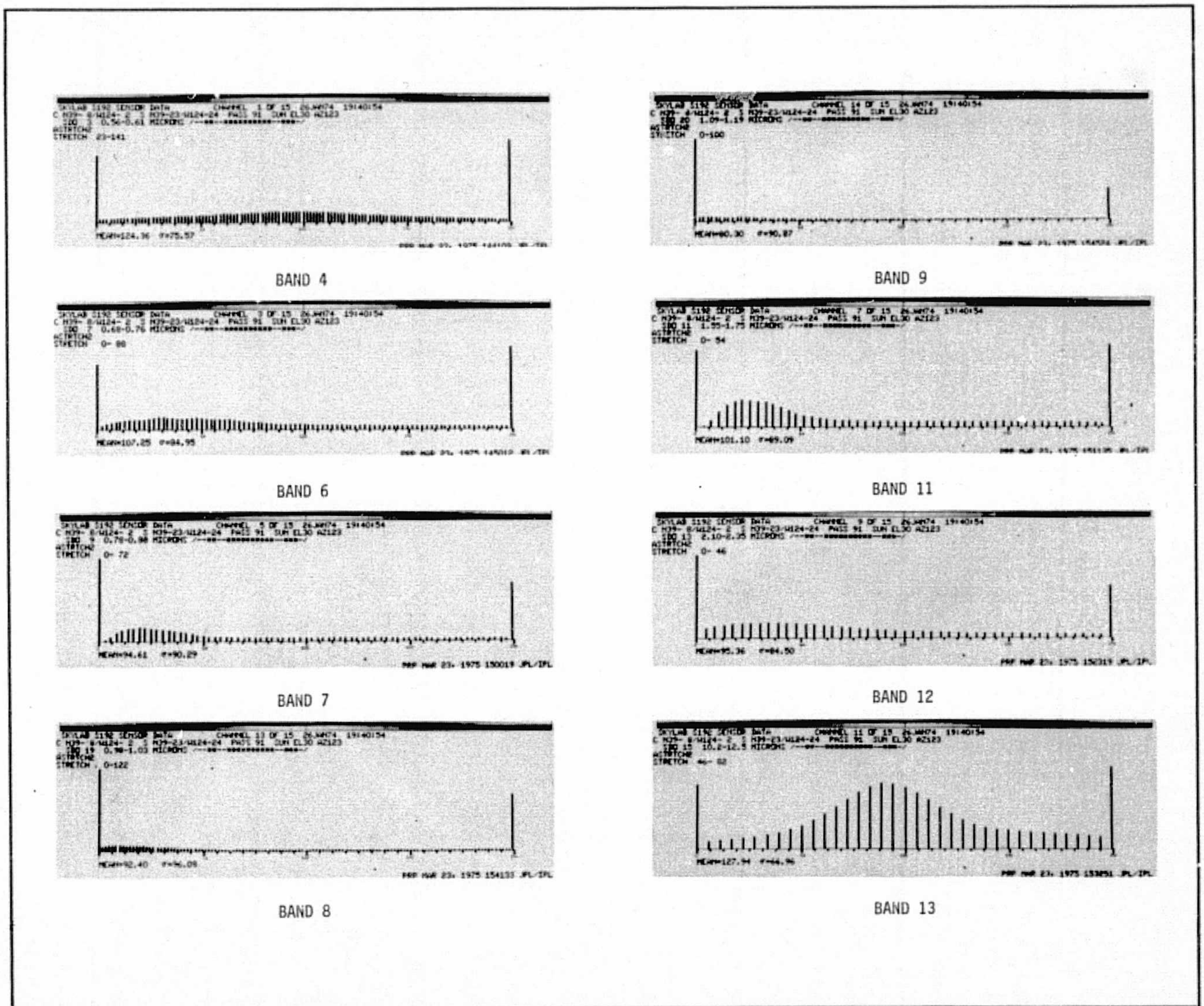


Figure 3-4. Histograms for S-192 Multispectral Scanner Imagery (see Figures 3-5 and 3-6).

Annotation:

1. SKYLAB Experiment, channel no. of available channels, date, GMT (-8 hrs. for PST).
2. Latitude and longitude of first line center pixal, latitude and longitude of nadir, pass, sun elevation and azimuth.
3. SDO - tape channel, spectral band, stars represent available channels out of possible 22.
4. ASTRTCH2 - contrast stretch program applied to data.
5. STRETCH - range of original brightness levels (digital numbers) represented in image. Upper and lower 3% of levels discarded and remaining levels stretched to 256 digital numbers (0-255).

   Histogram - gives number of digital numbers in the picture at each level.

6. Mean and standard deviation digital number.

7. PRP operator (Paluzzi), processing date, sequence number, Jet Propulsion Lab/ Image Processing Lab.

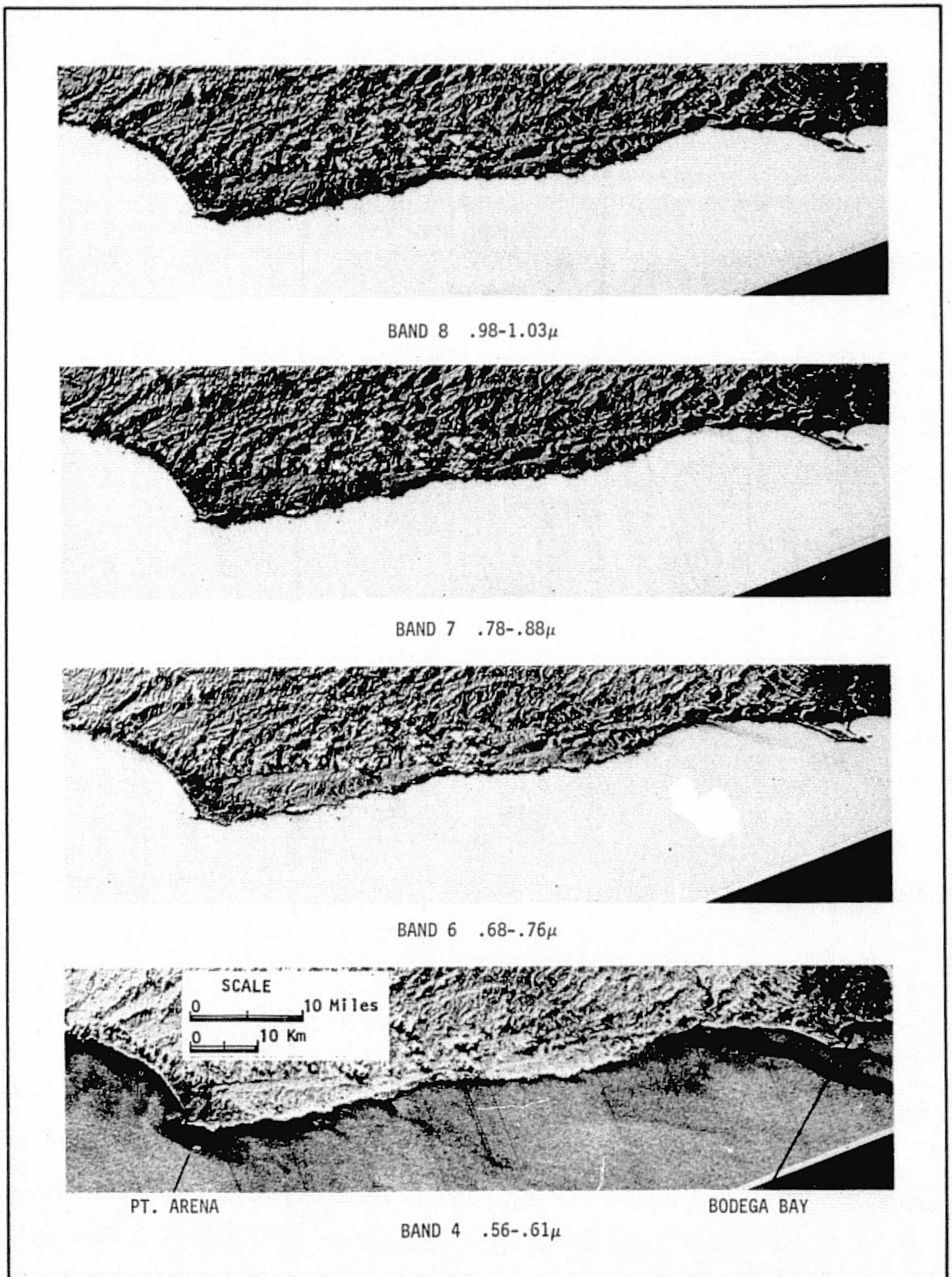
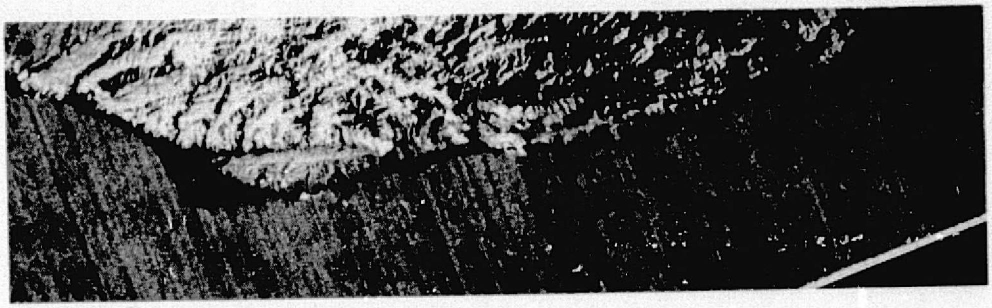
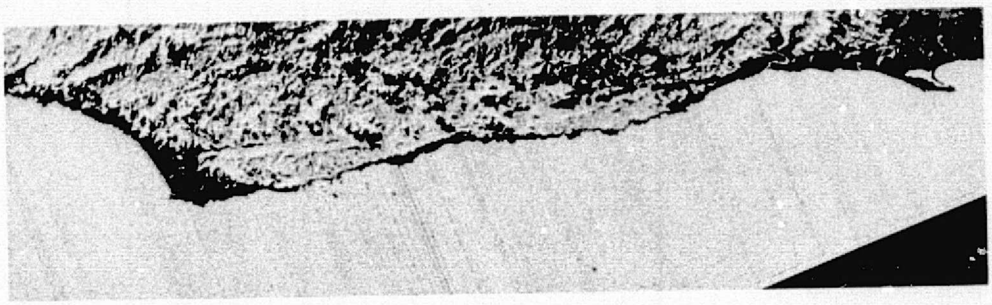


Figure 3-5. S-192 Imagery - Pt. Arena to Bodega Bay, California

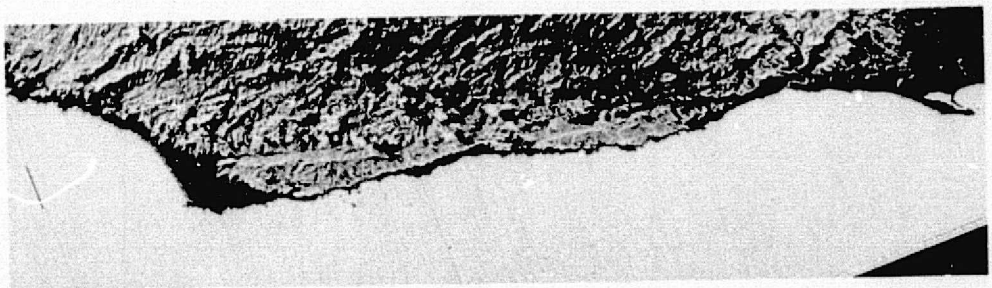
Bands 4, 6, 7 and 8 from the multispectral scanner. These unrectified images show the coastline north of San Francisco. Sediment discharge from the Russian River above Bodega Bay and the Garcia River at Pt. Arena is enhanced in Band 4 (green-yellow). Band 6 (red) shows surface materials only. See Figure 3-4 for brightness level histograms. NASA, SL4, S192, 19:40:54, 26 Jan 74.



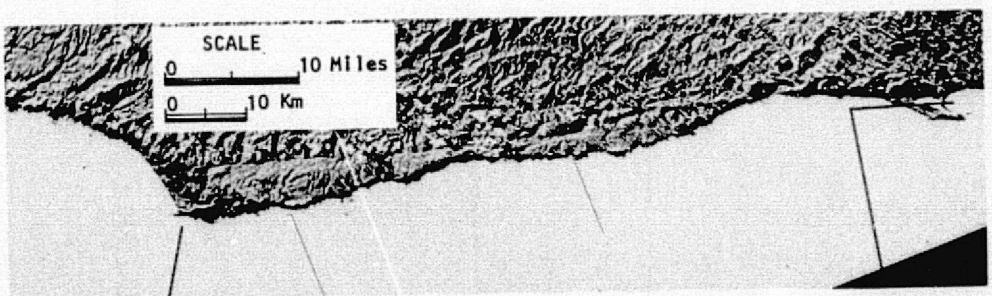
BAND 13 10.2-12.5μ



BAND 12 2.10-2.35μ



BAND 11 1.55-1.75μ



PT. ARENA

BODEGA BAY

BAND 9 1.09-1.19μ

Figure 3-6. S-192 Imagery - Pt. Arena to Bodega Bay, California

Bands 9, 11-13 from the multispectral scanner. Bands 9, 11 and 12 all infrared bands, show no water detail. Band 13 in the thermal infrared shows a slight brightness level differential in the water area off the Russian River mouth just above Bodega Bay. See Figure 3-4 for brightness level histograms. NASA, SL4, S192, 19:40:54, 26 Jan 74.


IMAGE S-192, SAN FRANCISCO BAY
PICTURE OF SAN PABLO BAY WAS
AT 1141 PST. IT IS A
IN THE NEAR INFRARED WHICH
REALEASE EFFECT AS SEDIMENT
RIVER WATER ENTERS SAN PA BAY
IN THIS NEGATIVE PRINT THE
THE HIGHEST PERCENT OF
DASHED AND DOTTED LINES ARE
PREDOMINANTLY RIVER WATER AREAS AND THE
OCEAN WATERS. NASA, SL4, S192, 19-41-10. 26 Jan
S = SUSPENDED SEDIMENT
= BOUNDARY
= APPROX. BOUNDARY
SCALE
0 6 MILES
0 5 10 KILOMETERS
SACREMENTO R.
MARE ISLAND
CARQUINEZ STRAIT
SAN PABLO BAY
S
RICHMOND
TIBURON
N

Figure 3-7.

4.0 SKYLAB IMAGERY

The details of the Skylab experiments and film/filter combinations, spectral curves, etc. are detailed in a number of NASA publications and will not be repeated here. Those interested are referred to SKYLAB EARTH RESOURCES DATA CATALOG (JSC 09016) as a starting point. Other detailed sensor publications are listed in the reference list. The objective of this section is to show what type of imagery was available for this study and to indicate how each sensor or band was utilized during the interpretation phase. See Figure 4-1 for sensor summary.

The three Skylab Earth Resource Package (EREP) missions took place in May-June, July-September, and November 1973 to February 1974. The comprehensive overviews of the San Francisco Bay and northern California Coast were utilized in the analysis of the coastal processes. Imagery from S-190A (Multispectral PHotographic Camera), S-190B (Earth Terrian Camera) and S-192 (Multispectral Scanner) was provided by NASA. The most useful information on coastal processes information resulted from the detection of suspended sediments. The sediment acts as a tracer which can be used for the analysis of: sediment transport, current dynamics, deposition and erosion, tidal phasing and pollutant distribution. The area of maximum reflectance shifts from the blue for clear water toward the green as suspended sediment content increases. The peak reflectance was near 0.55 microns for the heavily sediment laden water image in January 1974. For this reason the S-190A bands in the green (.5 - .6 microns) and the red (.6 - .7 microns) provided the most useful information on suspended sediment. The color photography from the S-190B experiment, however, proved to be excellent because of both spatial and spectral resolution. Several plots of the spectral differences resulting from the changes in sediment content are included in this section.

	Filter microns	RESOLUTION Meters (feet)	SEDIMENT TRANSPORT	WATER COLOR (SPECTRAL INTERVAL)	TEMPERATURE	REMARKS Coastal Processes G = Good F = Fair P = Poor
S-190A Multispectral Photography Camera						
FILM						
EK 2424 - IR (B&W)	.7-.8	64 (210)	F	F		Minor Surface
EK 2424 - IR (B&W)	.8-.9	70 (230)	P	P		Land/Water Boundary
EK 2443 - Color IR	.5-.88	61 200	F	C		Surface Detail
SO 356 - Hi Res Color	.4-.7	36 (120)	G	G		Excellent Detail
SO 022 Pan X	.6-.7	30 (100)	G	G		Surface Detail
SO 022 Pan X	.5-.6	30 (100)	G	G		Detail, Shallow Penetration
S-190B Earth Terrain Camera						
SO 242 Hi Res Color	.4-.7 No Filter	18 (60)	G	G		Excellent Detail
S-192 Multispectral Scanner						
BANDS AVAILABLE						
4 Green - Yellow	.56-.61	80 (262)	G	G		Sediment Transport Water Penetration
6 Red	.68-.76	80 (262)	G	G		Surface Sediment
7 Infrared	.78-.88	80 (262)	P	F		Water/Land Boundary
8 Infrared	.98-1.08	80 (262)	P	P		Water/Land Boundary
9 Infrared	1.09-1.19	80 (262)	P	P		Water/Land Boundary
12 Infrared	2.10-2.35	80 (262)	P	P		Water/Land Boundary
13 Thermal Infrared	10.2-12.5	80 (262)	P	P	F	Noise. Some Thermal Differentiation

NOTE: The remarks pertain to details of coastal processes detectable on the indicated sensor.

Figure 4.1. Sensor Summary

Figure 4-2 San Francisco Bay - Multispectral S-190A Series, SKYLAB 2

This set of multispectral pictures were taken at 1206 PST on June 2, 1973. The spectral bands are: (1) .5-.6 microns (green), (11) .6-.7 microns, (red), (III) .7-.8 microns (near infrared), and (IV) .8 - .9 microns (infrared). Bands 1 and 2 were taken on Pan X film and 3 and 4 on infrared black and white film. Clouds cover the offshore area and the Golden Gate Bridge but details in the Bay are clearly seen.

The effect of the complex currents can be clearly seen in the patterns that are emphasized by the various multispectral pictures. The South Bay tidal transmission is faster than the North Bay. In this example, the South Bay has slowed down and was nearing slack water. The clearer ocean water was visible in band II as it was forced past Angel Island northward to the Carquinez Strait area. Sediment laden waters from previous tidal phases were present in the South Bay where it emphasizes complex mixing patterns. Between Oakland and San Francisco a poorly defined linear pattern occurs in the south flowing tidal waters. This front was at the point where the Bay opens up after the constriction of the South Bay entrance. Under the San Mateo Bridge the maximum suspended sediment is concentrated to the west where the shipping channel is maintained.

For analyzing sediment transport and the effects of currents, the green and red bands have been most useful. The overall suspended sediment distribution is most clearly seen in the green band (.5-.6 microns) which reveal surface and near-surface patterns. In the picture of the Bay in the red bands are the most useful in marshland studies and in detecting the land water boundaries.

This set of pictures was taken 1½ hours before high tide which occured at 1336 at the Golden Gate Bridge. The height of the tide was 1.35 m (4.5 feet) at the time of this Skylab overpass with the predicted height as 1.6 m (4.8 feet) 55 minutes later. Maximum flood current took place 40 minutes before this picture at a velocity of 2.4 meters/second. The Golden Gate current at the time of this picture was still close to 2.3 meters/second.

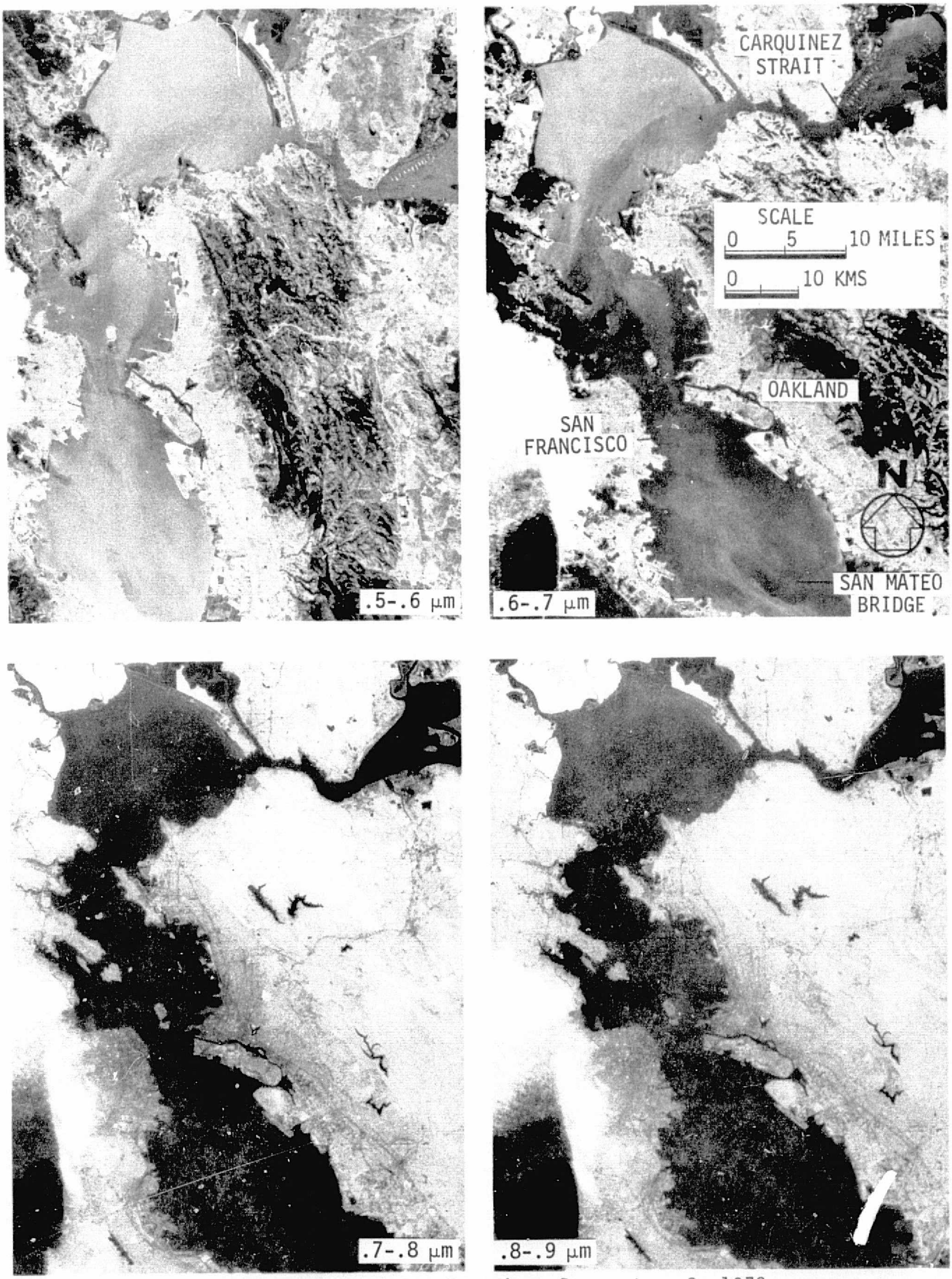


Figure 4-2. SL-2 San Francisco Bay - June 2, 1973
NASA, SL2, S190A, 101, 02 June 73

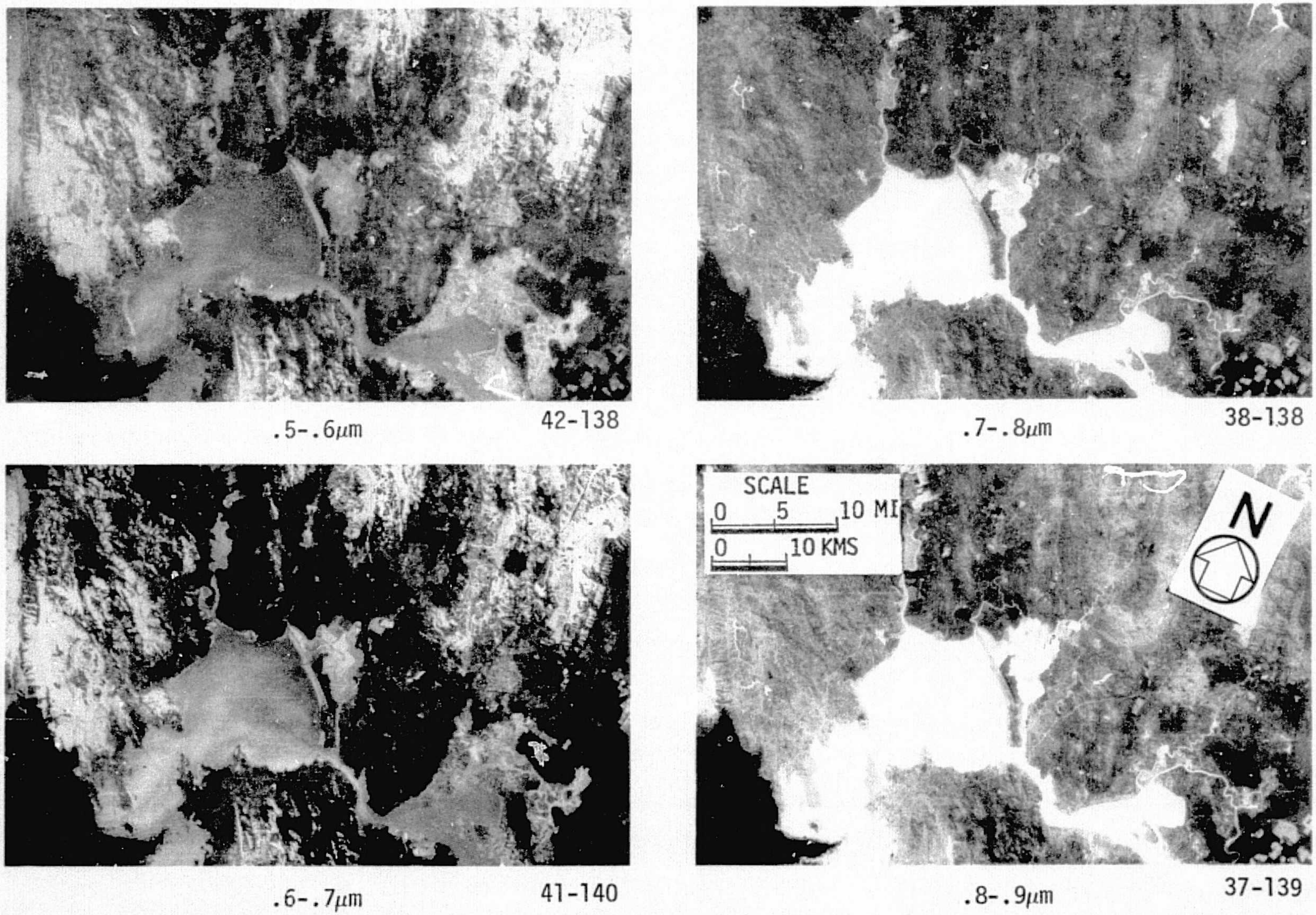


Figure 4-3. San Pablo Bay - September 12, 1973. SL-3

Negative prints (clouds black) of the northern section of San Francisco Bay during low sediment discharge from the Sacramento-San Joaquin River. Distribution of surface sediment along the south shore near Pinole Point is most obvious in the .6-.7 micron band. Low sediment discharge through Carquinez Strait is apparent when compared to the SL-4 January 1974 imagery. NASA, SL3, S190A, 12 Sept 73.

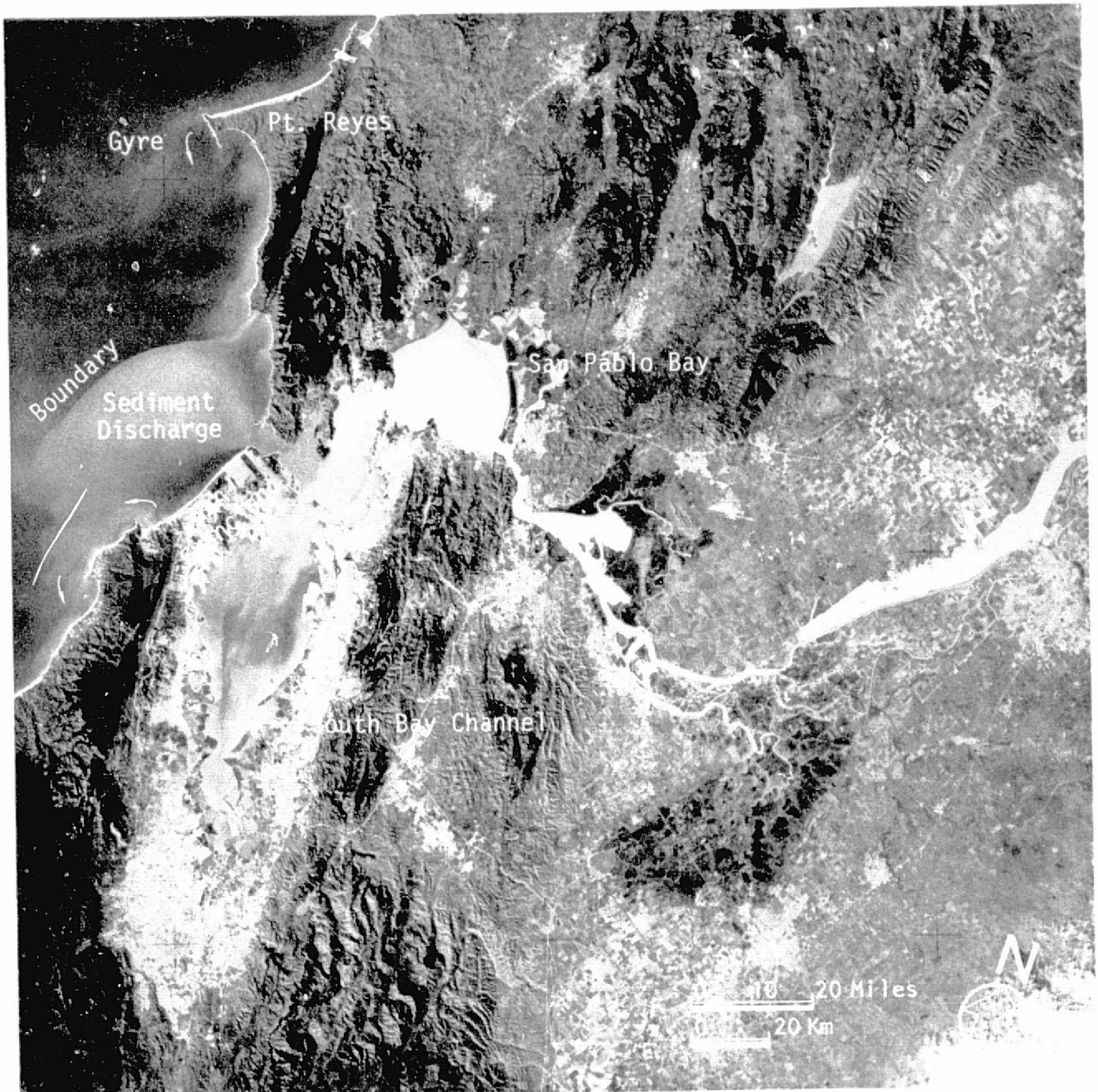


Figure 4-4. Suspended Sediment Off Central California.

This blue-green spectral band picture is the optimum SKYLAB sensor for suspended sediment detection. The spectral reflectance of the surface sediment is in or just below the range of the filter (.5-.6 micron) on this camera. On January 26, 1974, discharge into the San Pablo Bay was near its yearly peak. NASA, SL4, S190A, 78-71, 26 Jan 74.

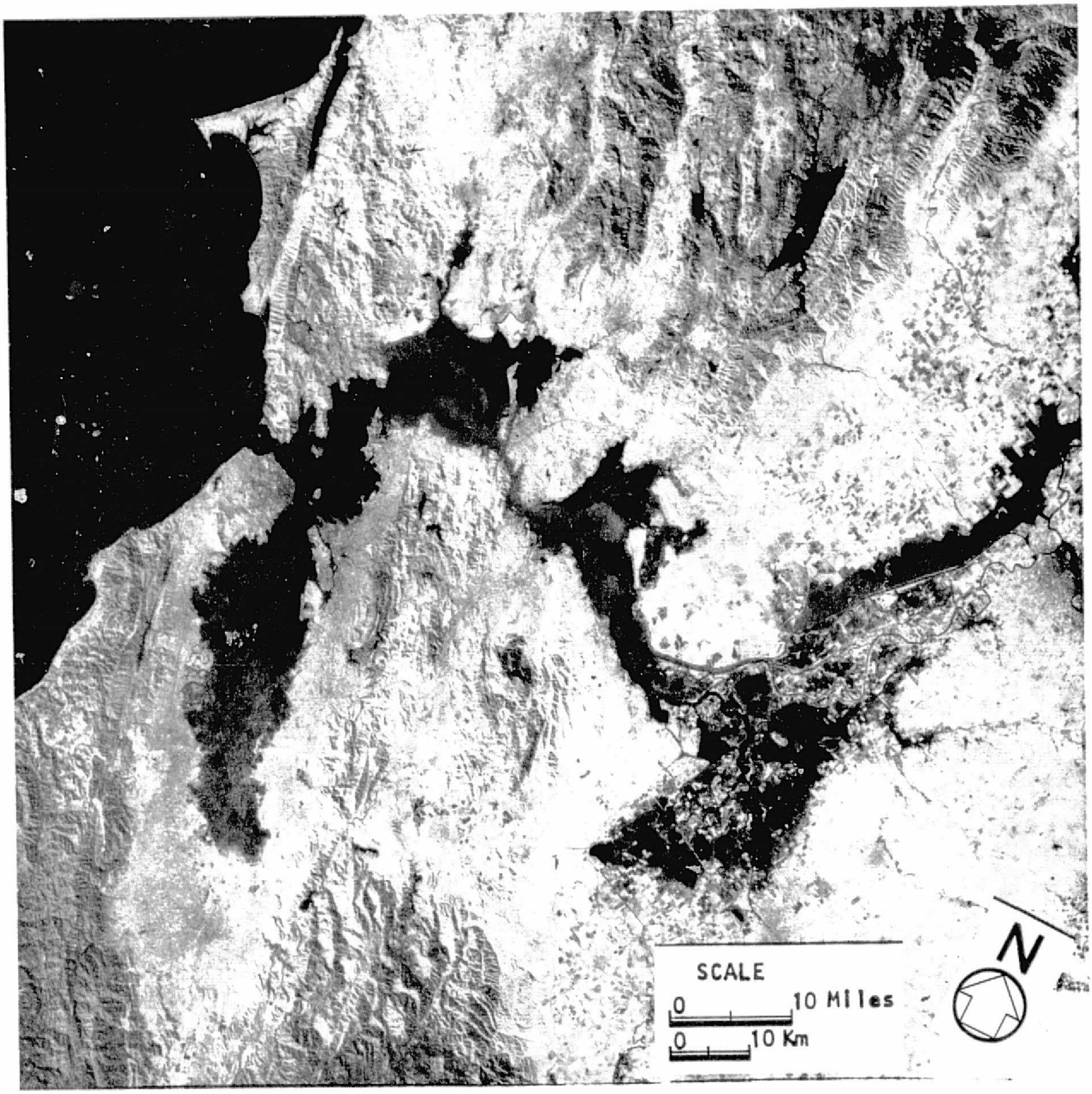


Figure 4-5. Near Infrared Picture of San Francisco Bay.

Most surface sediment is not distinguishable except at the location of maximum volume. The patterns in the north Bay are easily distinguished. Water-land boundaries are also well defined. .7-.8 micron filter and EK2424 film. NASA, SL4, S190A, 73-71, 26 Jan 74.

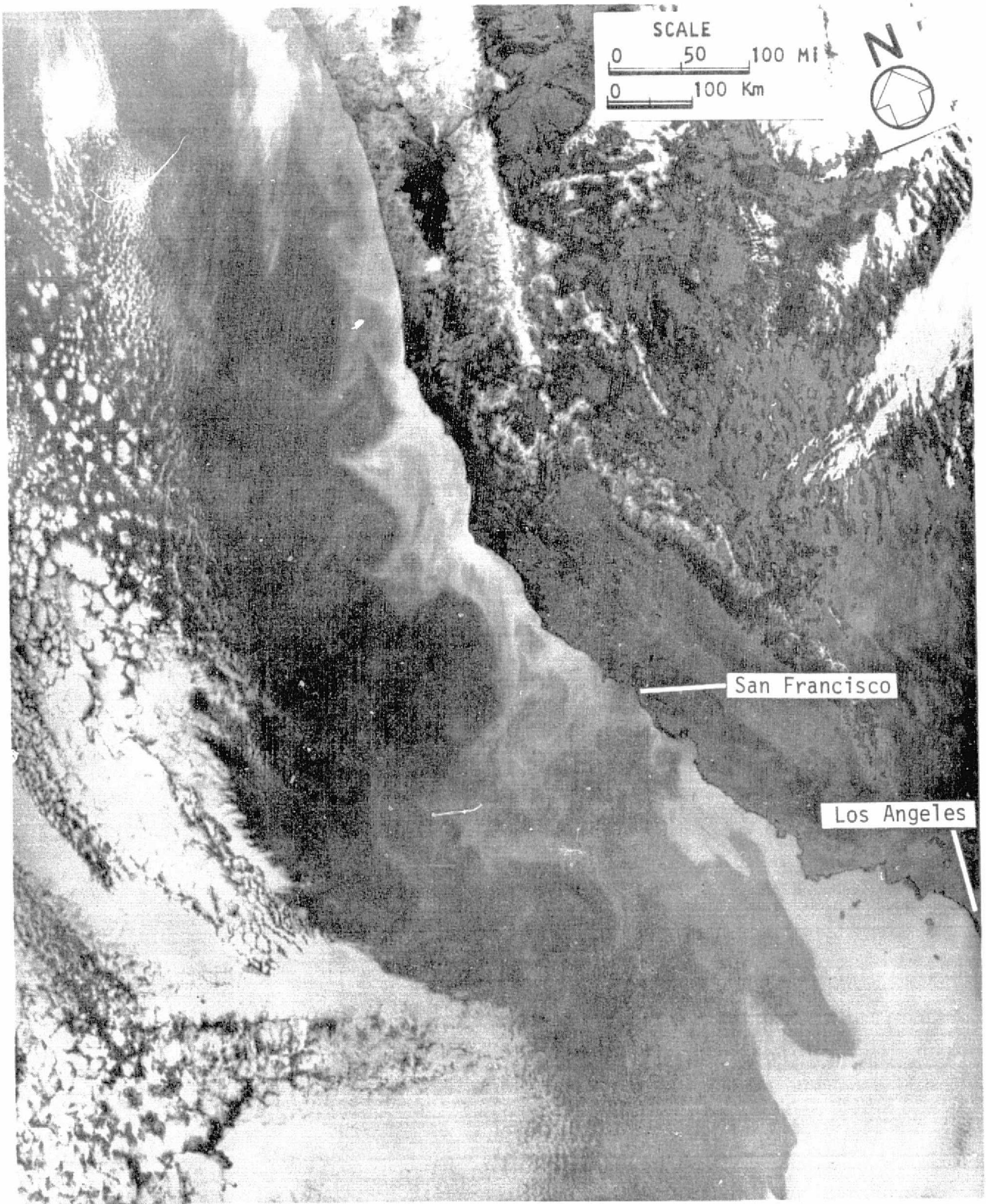


Figure 4-6. West Coast Sea Surface Temperatures NOAA-3.

This infrared thermal image was taken September 11, 1974 by the NOAA-3 satellite. It shows qualitatively the sea surface temperature distribution. The light gray along the coast is 14°C and the dark gray offshore represents temperatures of 20°C. A definate upwelling along the coast is obvious in this picture. (Breaker, 1974) NOAA-3 11 Sept 74.

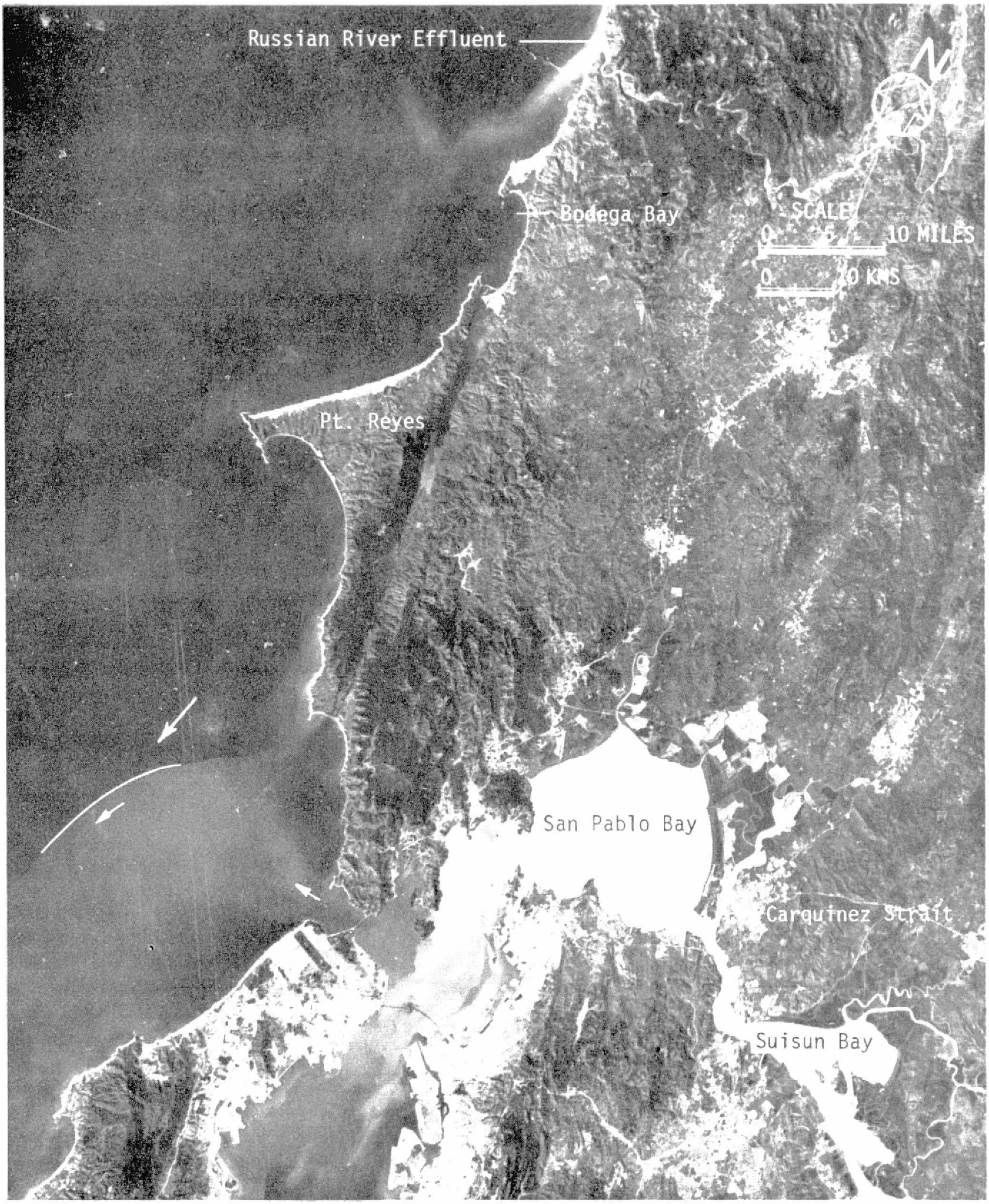


Figure 4-7. Russian River to San Francisco SL4 RL77 071.

Discharge of large volumes of sediment laden water through the Carquinez Strait is visible. The distribution of the waters after the hydraulic release in San Pablo Bay is observable. This results in transport evidence that can be utilized in predicting sites of potential deposition and dredging problems. NASA, SL4, S190A, 77-71, 26 Jan 74.

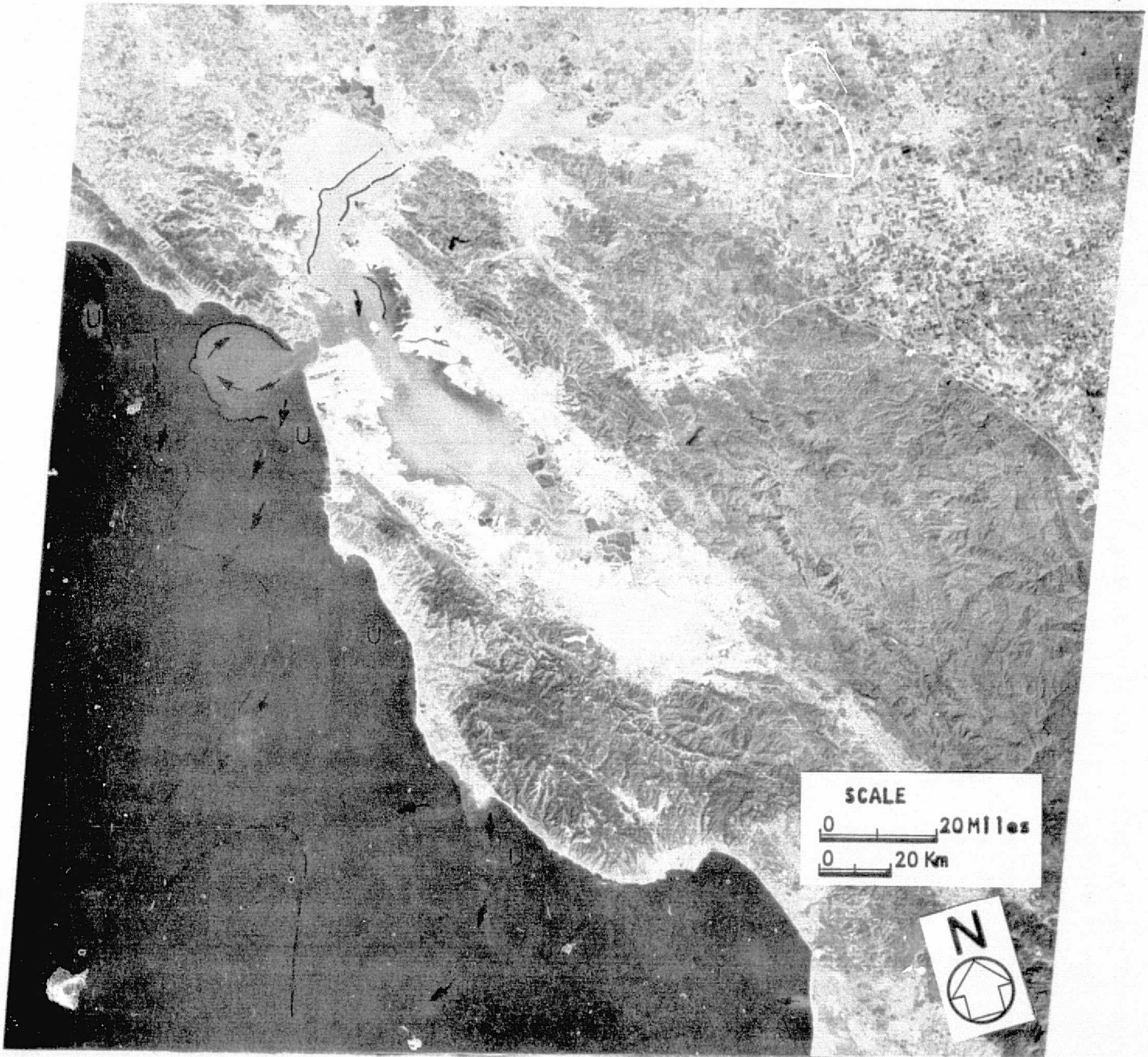


Figure 4-8. San Francisco Bay ERTS-1, April 4, 1973.
NASA ,ERTS-1 (LANDSAT-1), 1255-18183-5, 04 April 73

ORIGINAL PAGE IS
OF POOR QUALITY

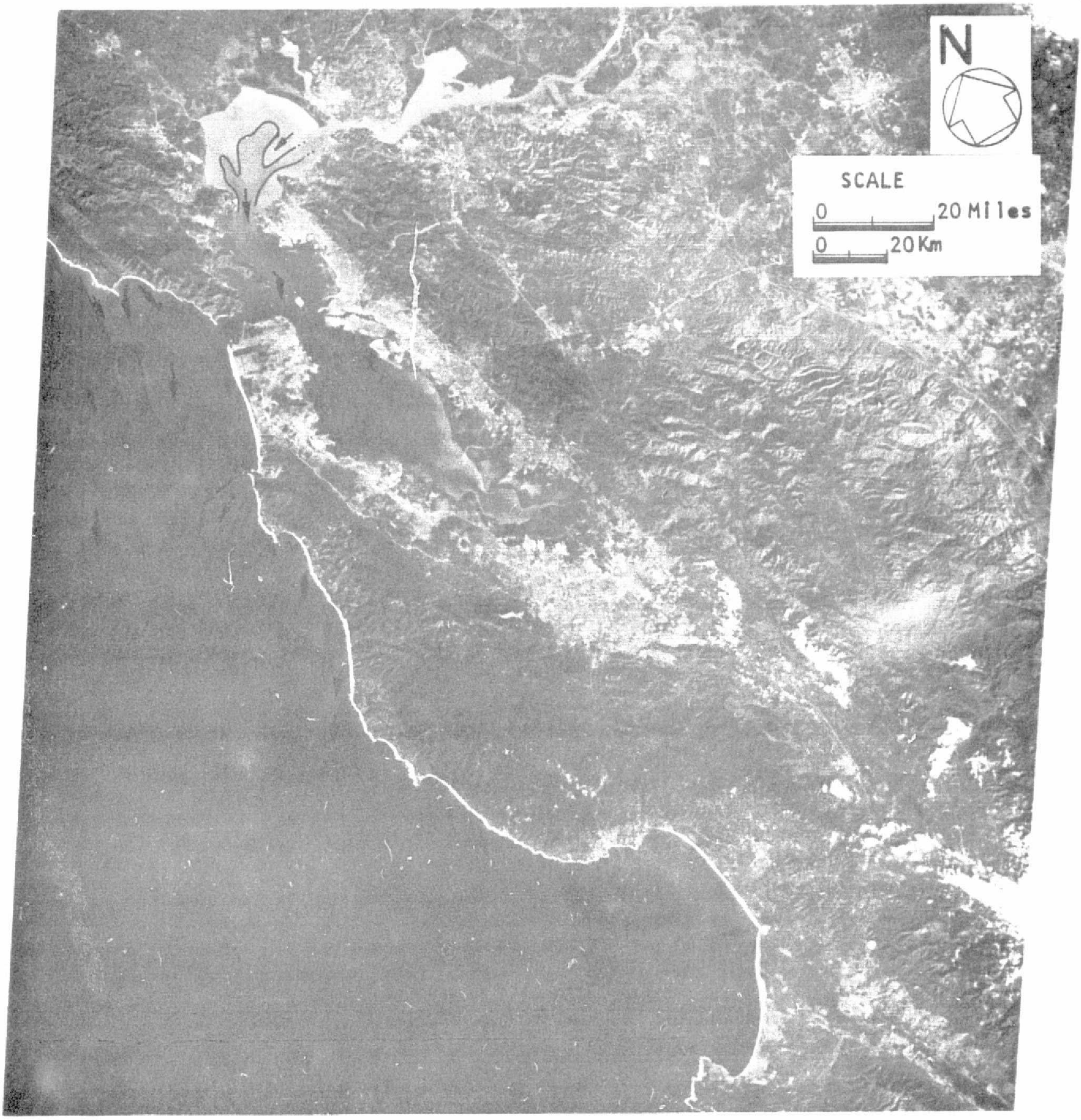


Figure 4-9. San Francisco Bay ERTS-1, December 30, 1973
NASA, ERTS-1 (LANDSAT-1), 1525-18145-5, 30 Dec 73

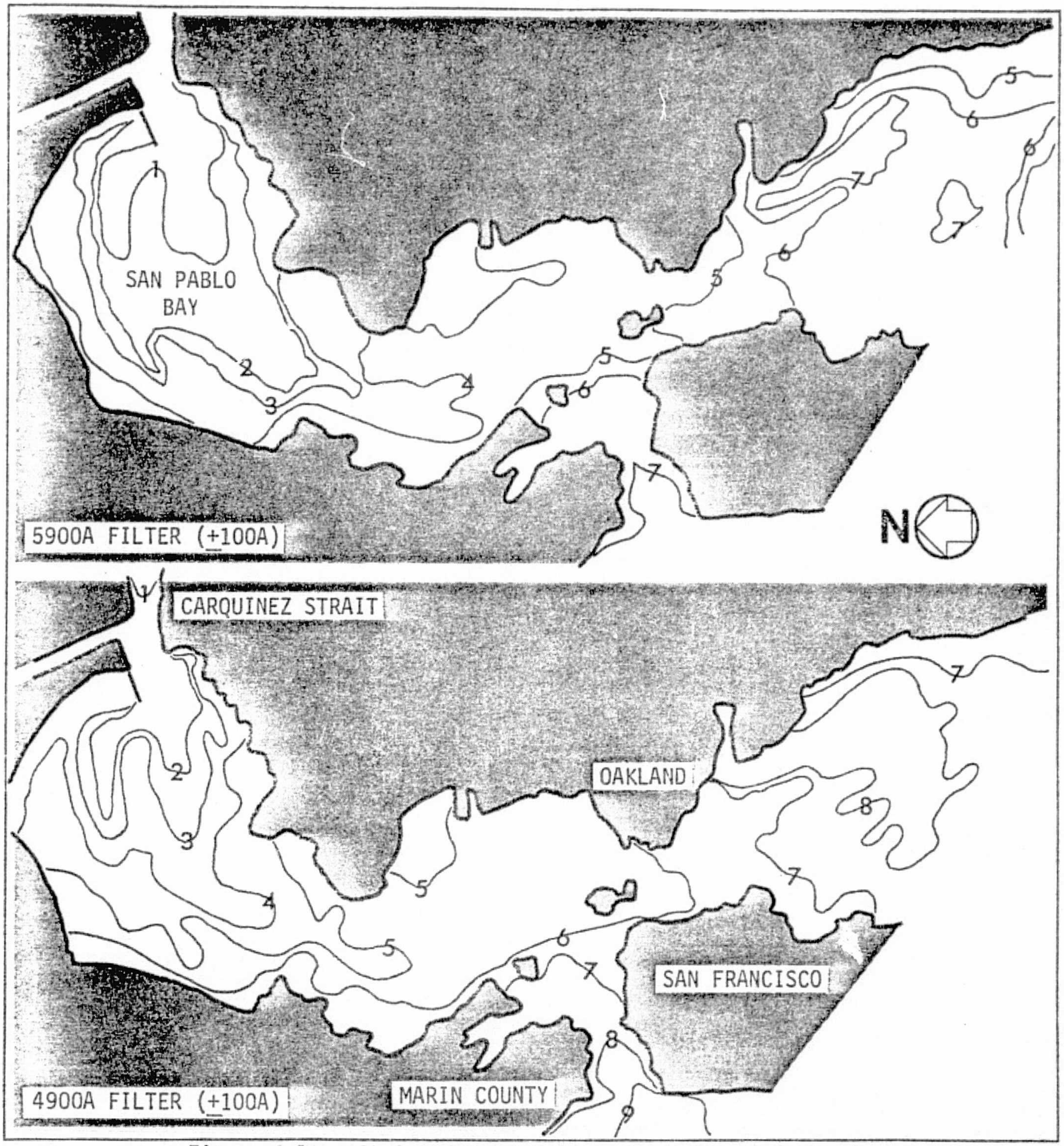


Figure 4-10. Skylab Color Photography Sediment Analysis (SL4-92-337, January 26, 1974, 1141 PST)

These plots of San Francisco Bay were made utilizing narrow-band filters and a Data Color densitometer. Contours representing amounts of surface suspended sediment, 1 maximum to 9 minimum, near Carquinez Strait indicate that the spectral peak of the San Francisco Bay material is near 5900A. A wider distribution of low numbered contours in the San Pablo Bay area on the 5900A plot are present. This illustrates the spreading suspensates issuing from the Sacramento-San Joaquin Rivers into the bay. Use of this filtering technique represents a valuable tool in analyzing surface mixing patterns. NASA, SL4, S190A, 92-337, 26 Jan 74.

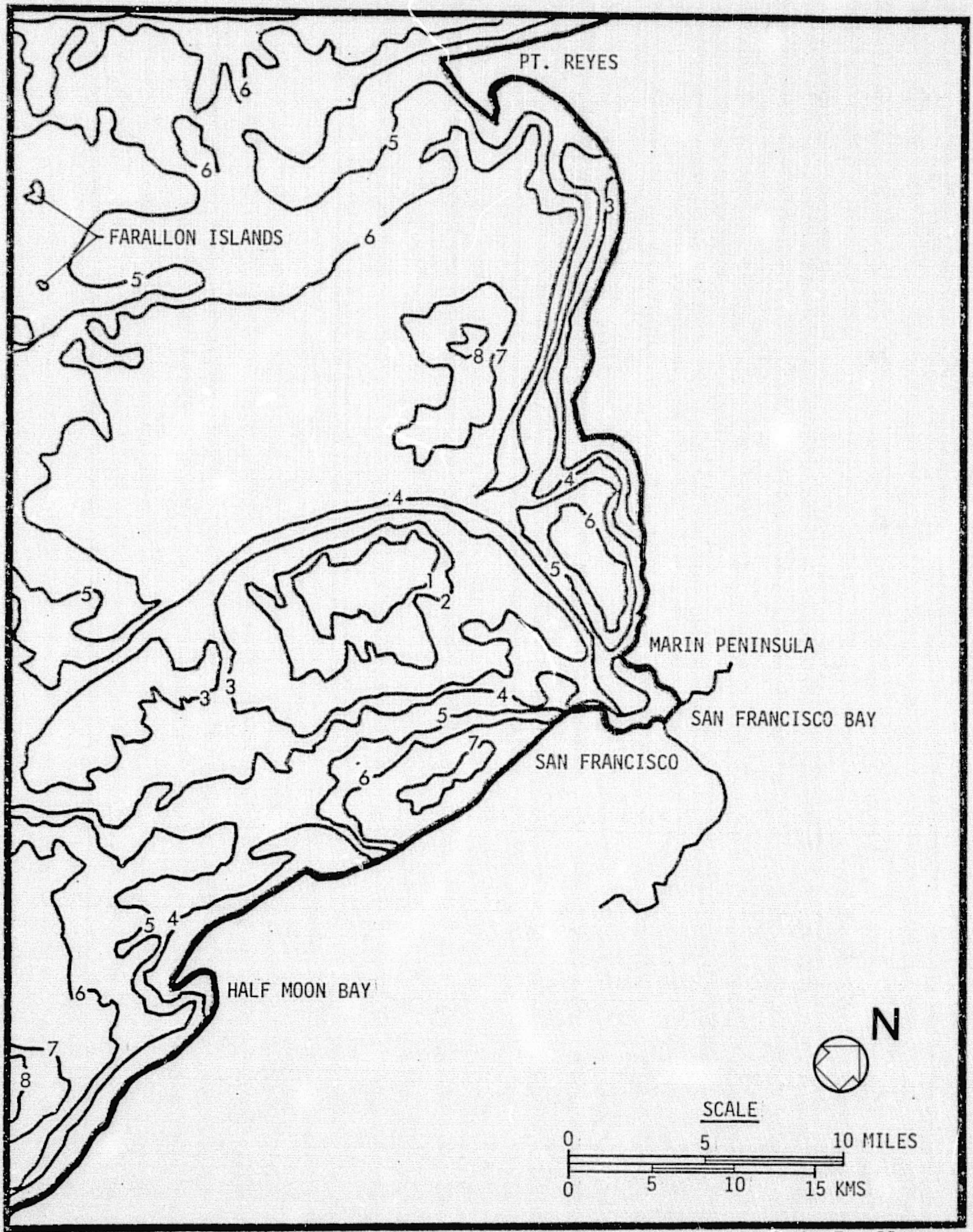


Figure 4-11. Automatic Plot of Surface Sediment Distribution- Gulf of the Farallones.

Digitized surface sediment distribution is automatically plotted from SKYLAB 4 S-190A Color (SO356) picture collected January 26, 1974, at 11:41 PST. The contour levels vary from 1 to 8 and indicate decreasing amounts of surface suspended sediment. NASA, SL4, S190A, 76-71, 26 Jan 74

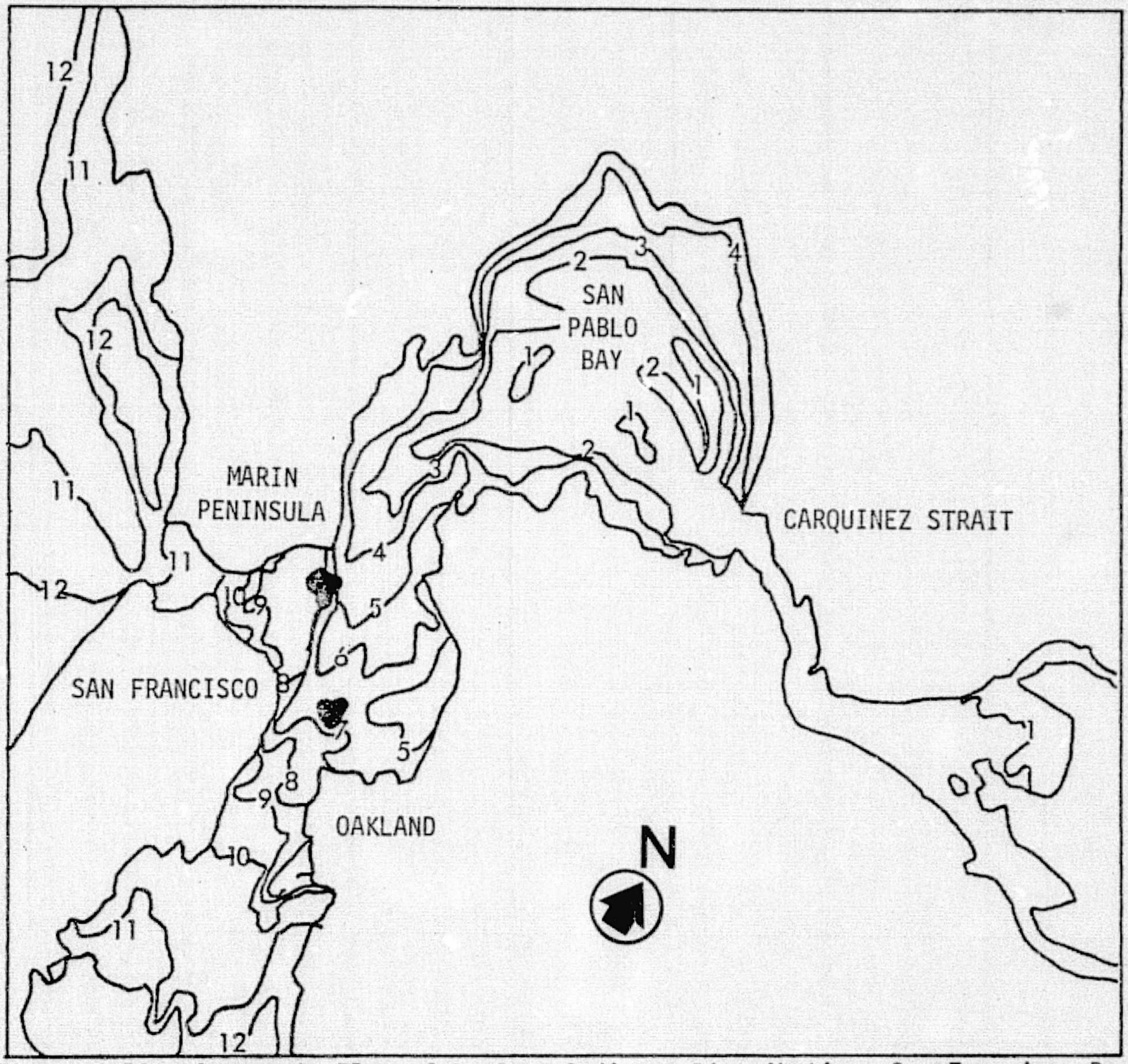


Figure 4-12. Automatic Plot of Surface Sediment Distribution, San Francisco Bay.

Automatically plotted from SKYLAB 4, S190B Color S0242, picture collected January 26, 1974 at 1141 PST. The contour level plotted by computer on a plotting table. Contour levels vary from 1 to 12 indicating decreasing amounts of surface suspended sediment. NASA, SL4, S190B, 26 Jan 74.

5.0 IMAGE ENHANCEMENT

5.1 ENHANCEMENT TECHNIQUES

Transparencies were analyzed and enhanced using the following equipment:

Data Color System	Spatial Data Model 703
Microdensitometer	Joyce Loebl MK III CS
Additive Color Viewer	I^2S Model 6000
Isodensity Tracer	Tech Ops Model 608

<u>False Color Density Slicing</u>

Two false color density-slicing techniques were employed on the Skylab imagery: the data color system and Tech Ops-Joyce Loebl Scanning Microdensitometer. In many cases, small density changes were not visibly detectable, yet these changes could have been the key to the proper analysis of the image. These devices provided quantitative methods of determining film density variation as well as providing an enhanced false color display. Both systems operate on film transparencies as input data.

Data Color System

The Data Color System uses a standard 525-line video camera to scan and capture density information contained within transparencies or hardcopy prints. The resulting video signals are quantitatively digitized into 32 discrete gray scale range. Each density level is related to a unique code to produce a color TV display which can contain up to 32 colors. Such a system is programmable in the sense that the color range can be either shifted up or down over a total density range, or expanded and compressed to encompass more or fewer density ranges. Density slicing provided a rapid interactive technique to quantitatively evaluate each image within the context of targets of interest. A planimetric readout of any single or multiple combination of colors (densities), permitted the determination of the areal extent of features.

Microdensitometer/Isodensity Tracer

The Tech Ops-Joyce Loebl device is both a scanning microdensitometer and an isodensity plotter. This system records a total of 64 levels of gray with considerably higher spatial resolution than the Data Color System. The output of the isodensitracer mode is a two-dimensional density map which is color coded. In the scanning microdensitometer mode, the quantified density values read along a single scan line are plotted as a line trace of density versus distance along the scan line.

Both devices displayed application to enhance imagery for the location and delineation of sediment plumes and associated currents. Processing of color IR and IR thermal data resulted in isothermal contours which were analyzed and correlated with the results of other photo-interpretation processes.

Optical Image Enhancement

Various Optical Image Enhancement techniques were attempted on Skylab imagery. Techniques were applied using the International Imaging Systems (I^2S) additive processor and the Space Optics Spatial Filtering System. Typically, information is masked in a broad band spectral photograph, thus the advantage of multispectral photography. Photographs taken in different parts of the spectrum contain information unique to its specific spectral band. A set of multispectral images covering the total spectrum can be added with appropriate control of the individual color sensation of brightness, hue and saturation. The resultant image is an enhancement of the original scene as described in the following multicolor additive processing section.

Likewise, spatial patterns contained within a signal multispectral image may tend to mask a feature of interest. The use of a spatial filtering system can be employed to remove specific spatial patterns without altering those of interest.

Multicolor Additive Processing

From additive color theory, a composite color image may be produced from photographs taken in different parts of the spectrum under certain conditions. If four different monochromatic spectral light sources are used to illuminate four positive transparencies taken in the respective regions of the spectrum, and these spectral positives have images in identical spatial locations relative to their respective principal points, and if these images are optically projected one upon the other so that no mis-registration exists, a composite color rendition of the scene will be obtained. The source of illumination for each of the four spectral images must be of comparable wave length and purity, because it in turn controls the color sensations of brightness, hue, and saturation. If the minimum perceivable density difference is about 0.02, about 200 shades of gray can be differentiated on a black and white photograph, whereas under certain conditions, more that 7,500,000 color differences can be perceived.

Photo Reproduction

Photographic processing and reproduction techniques were employed throughout the program. Past experience gained during the ERTS study indicated that the following specific photo-reproduction technique be utilized:

A) Black and white prints and/or enlargement of selected ERTS scenes are exposed and processed as required. The laboratory was located adjacent to the data handling and interpretation facility for quick turnaround.

B) Duplicate negatives and/or positive transparencies are made as required. Mean density and contrast are controlled to optimize resulting images for a particular processing procedure.

C) Image color enhancements are photographed and processed utilizing photographic techniques which emphasize features of interest (i.e. suspended sediment, estuaries, riverine discharge).

The performing parameter of the systems used during these reproduction tasks have been found to be of high quality. All system optics displayed a high MTF, far beyond any spatial frequencies typical of study targets.

5.2 INTERPRETATION COSTS

Technique	Cost
1. S-190A and B color and black and white frame by frame manual interpretation for coastal processes. Overlay of features detected and drafting for publication.	$350
2. S-192 processing reformatting to VICAR (JPL) format and image processing of black and white print with density histogram.	$450
3. Color composite of merged and linearly stretched computerized image utilizing the Image 100. Reformatting is assumed to have been completed in the previous step. Output is hard copy color print of enhancement.	$250
4. Combination of 4 NASA supplied 70mm frames into additive color viewer print of Skylab site. Output is a hard copy color print.	$ 85
5. Data color densitometer analysis of one Skylab 70mm frame. Output is a hard copy color print of the enhancement.	$ 85
6. Microdensitometer analysis of one Skylab frame. Line scan across area of interest and interpretation of scan.	$ 75
7. Isodensity trace of 70mm frame. The output is a hard copy plot and a brief interpretation of the plot.	$180

6.0 CONCLUSIONS

1. In San Pablo Bay the patterns of dredged sediment discharges were plotted over a three month period. It was found that lithogenous particles, kept in suspension by the fresh water from the Sacramento-San Joaquin, were transported downstream to the estuarine area at varying rates depending on the river discharge level. To measure the transport in San Pablo Bay, dredged sediments were marked with iridium before discharge near Carquinez Strait. For the months of May, June, and July 1974 the movements of these tracer sediments were plotted after collection and processing, from 82 stations within the bay. This information was matched with movements predicted from Skylab interpretation. Correlation patterns resulted. Special note was made of areas of heavy sediment concentration resulting from the large sediment discharge of the 1974-1975 winter season.

2. The Skylab project collected California coastal imagery at limited times and not at constant intervals. Resolution, however, helped compensate for lack of coverage. Increased spatial and spectral resolution provided details not possible utilizing Landsat imagery. The S-190A multispectral photographic resolution was about 25 to 40 meters (82 to 131 feet) and the S-190B about 12 to 25 meters (39 to 82 feet). Resolution of the S-192 scanner data was difficult to determine because of noise and the conical scan. It appeared to be about 80 meters (262 feet).

3. The Corp' Pollutant Distribution Study is an on-going San Francisco Bay investigation. This study has the objective of mapping horizontal and vertical distributions of certain organic and inorganic contaminants. As part of this investigation, physical estuarine processes as well as physical factors affecting the distribution of these contaminants continues to provide a simplified physical picture of contaminant dispersion patterns. Skylab imagery shows these surface distribution patterns in detail. Visible hydraulic and sediment transport patterns provide a pertinent set of data illustrating dynamic water surface processes.

4. The S-192 data was reformatted at the Jet Propulsion Laboratory, Pasadena. Band by band image density stretching was utilized to enhance sediment discharge patterns entrainment, boundaries, and eddys. Color composites of linearly stretched and merged bands 4, 6 and 7 were made for further ease of coastal process analysis. The only problem encountered was in surface temperature analysis. Lack of resolution and noise prevented mapping of known San Francisco Bay and coastal surface temperature differences.

5. The January 26, 1974 Skylab 4 imagery of San Francisco Bay was taken during an exceptionally high fresh water and suspended sediment discharge period. A three pronged surface sediment pattern was visible where the Sacramento-San Joaquin River entered San Pablo Bay through Carquinez Strait. The three prongs extended to areas where maximum deposition historically occurs (i.e.,

central channel, southeast shore near Pinole Pt. and northwest flats near the Petaluma River mouth). The four S-190A black and white photographic bands showed this pattern in detail. The S-190B color photography was excellent for spectral and spatial resolution. Spectral analysis of the imagery indicated that the sediment reflection peak was near .55 microns. Wind from the NW was moving surface waters into the southeast Bay near Pinole Point.

6. Measurements of the suspended sediment load passing through the Carquinez Strait were made during January 1974. These measurements were compared with the heavy concentrations occurring on January 26, 1974. In the center of the channel the concentration was approximately 250mg/liter. A total of about 6.9 million tons of material passed into the San Francisco Bay during this 1973-1974 season. Analysis of the S-190A imagery indicates a reflectance shift toward the green from the blue as sediment load increases. Thus the excellent detail in the 0.5-0.6 micron and 0.6-0.7 micron bands.

7. Dredging may be required in the Berkeley flats area of San Francisco Bay. Use of satellite and aircraft information in this area will be beneficial because the sites of shoaling and deposition are detectable using Skylab imagery. Cost savings using Skylab data would vary with the placement and extent of required dredging but it is possible that several million dollars savings or better benefit could result from correct operation and dredge placement.

8. Nearshore patterns detectable on the Skylab imagery provide evidence for seasonal current directional changes. On the Skylab imagery collected on Janaury 26, 1974, south moving currents off Pt. Arena were interrupted by numerous upwellings and nearshore northerly currents. This is near the end of the Davidson current season which usually ends in February. At this time the south moving California Current becomes dominant as the California Current season starts. Interpretation of aircraft imagery and coastal current information only would not indicate this changing pattern.

9. The techniques outlined in this report should be applicable for coastal and estuarine processes studies in other areas of the world. A suspensate concentration of approximately 2mg/liter is quite sufficient to tag a surface current system and by using progressively longer wavelength filters, the surface structure of currents with over 250mg/liter can be imaged. The only areas which would not be suited for this type of technique would be those tropical or extremely clear waters where little or no suspensates occur from erosion, runoff or plankton. However, the option to thermally image these clear water areas exists. California has been an excellent coastal area for demonstrating the satellite systems for coastal and estuarine processes studies because of the varied types of coastal features that are encountered. To the north are rocky coasts with silt laden streams and rivers. The southern coast is more toward the long sandy beach type with eroding coastal bluff formations. The streams and rivers of Southern California are usually dry during the summer months.

7.0 RECOMMENDATIONS

1. On future experiments where thermal infrared is used, strive to eliminate noise and improve response to thermal reflectance. Differences in surface water temperatures of more than 2 levels were very difficult to determine. This is an area (San Francisco Bay) where thermal variations of 6 to 10°F might be expected.

2. Release S-192 type tapes with scan lines straight (normal to flight) rather than the conical line scan patterns. This would eliminate a great deal of software and hardware time in processing and enhancing the scenes.

3. For studies concerned with coastal and estuarine processes to be successfully carried out, we feel that various support activities are required. The most inportant aspect of remote sensing, that is often overlooked, is that the sensor platform must be capable, both spectrally and resolvingly, of imaging the parameters of interest. Once the sensor is determined to be adequate, the frequency of imaging must be compared to the various time frequencies that are characteristic of the coastal or estuarine processes of interests. Periods from years down to seconds are commonly encountered and the investigator must determine which are significant (e.g. tides and seasons) and which may be considered noise (e.g. sun angle and haze). If satellite systems are the primary imaging tool, aircraft flights may be utilized to increase accuracy and confidence in analyses by elimination of frequency dependent phenomena. Ground truth is another means of increasing confidence in analyses results, by monitoring coastal and estuarine parameters at statistically defined periods of time as dictated for important frequency dependent functions. Aircraft and ground data acquisition is considered essential not only for the time variabilities, but also for increasing the resolution and definition of analyses. What may only be conjecture in a satellite image, may be defined in an aircraft image and examined in a ground survey. Equivalent areas then may be inferred on the satellite imagery.

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